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ON-ROAD BRAKING AND CORNERING PERFORMANCE OF VARIOUS OFF-ROAD TIRE PATTERNS

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ABSTRACT

Ten sets of tires with nine different off-road tread patterns were tested on a paved surface using a towed, instrumented trailer to measure their cornering characteristics (wet and dry) and their braking performance (wet, full skid).

The data obtained and a method for rank ordering is presented.

Keywords

Tire test
Braking performance
Cornering performance
Radial tire

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INTRODUCTION

The adoption of radial ply tires by the military will present an ideal opportunity also to adopt a new tire tread pattern. Such a new tread pattern is desirable to make the radial tires easily identifiable in order to avoid, as much as possible, indiscriminate mixing of radial and bias tires, a recognized dangerous situation. A new pattern is also desirable to improve the traction characteristics of present military tires on wet pavements and to improve wear rates.

At present, there is no known theory or mathematical model, which will predict the performance of various tire tread patterns either on-or off- the highway. This program, therefore, investigated nine tire tread patterns which were selected by the U. S. Army Tank-Automotive Command (TACOM). This was the first step in a rather comprehensive program to develop a new military tread pattern which will improve on-road performance without degrading cross-country performance. Hopefully, this program will also obtain better insight into the part that tire tread patterns play in on- and off-road traction.

TEST PROGRAM

Two types of on-road tests were conducted: Measurements of tire cornering and tire braking forces. To conduct these tests at the loads desired, a special trailer was constructed (see Figure 1). This two-wheel trailer was provided with special linkages that would simultaneously yaw both tires in equal but opposite directions (see Figure 2). Both wheels were connected to an activator so that the yaw angle could be controlled remotely from the towing vehicle and the test wheel had an angular potentiometer mounted so that the angle could be measured and recorded. Mounted on the test wheel was a balance specially constructed

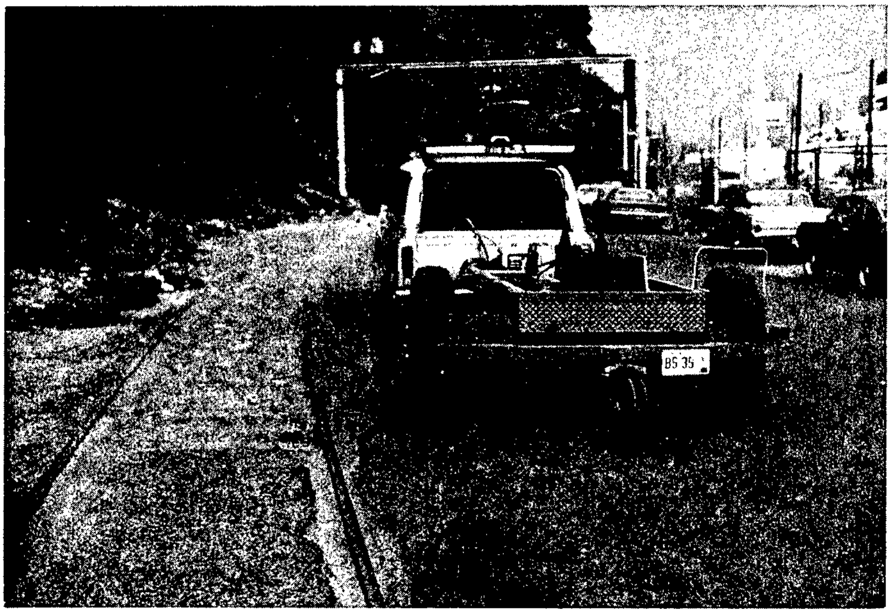


FIGURE 1. GENERAL VIEW OF TEST APPARATUS

FIGURE 2. TIRES UNDERGOING TEST ON DRY PAVEMENT AT LARGE TOE-IN ANGLE

which measured the forces normal to the wheel plane resulting from this yaw motion (see figure 3). Removable dead weights were employed to vary the test loads. Attached to the rear of the trailer was a "beta-wheel" which measured the yaw angle of the trailer with respect to its forward motion. This yaw angle may have been due to a "crown" on the road surface or high toe in/out angles when the tire cornering forces have "peaked" creating an unstable condition. A watering system, which directed water from the towing vehicle to the front of the test tires allowed testing under either wet or dry road conditions.

To measure braking traction, the trailer was supplied with air-actuated brakes. The same balance which measured the normal forces was also capable of measuring wheel torque. From this torque and the measured loaded radius (spindle height), the braking force could easily be calculated. The test operator controlled the brake mounted on the test wheel. For safety, the vehicle driver had a control which applied both brakes. By carefully regulating the air supply, the test operator could gradually slow down the test wheel until it stopped. The other tire remained free to roll and prevented the trailer from yawing excessively. One tachometer, mounted on the free wheel, measured the forward velocity of the trailer; another measured the speed of the braked wheel. A positive displacement pump, attached to the drive line of the vehicle insured a water layer thickness of 0.02 inches, regardless of test speed.

Ten different tires were tested. To avoid commercial identification they have been designated with the letters A though J. Pictures of their tread patterns are shown in Figures 4 to 13. All tires were 9.00-20. Tire I is the current, standard U. S. Army tire design on a bias ply carcass. Tire H also had a bias carcass. All other tires were of radial construction. All radial tires had a 14PR except tire J, which had a 12PR. The two bias ply tires had 8PR. To observe the influence of ply rating, tires G and J had the same tread pattern. (They may look slightly different in the accompanying photographs because the pictures were taken after the tests on tire J were completed, but before those on tire G had started.)

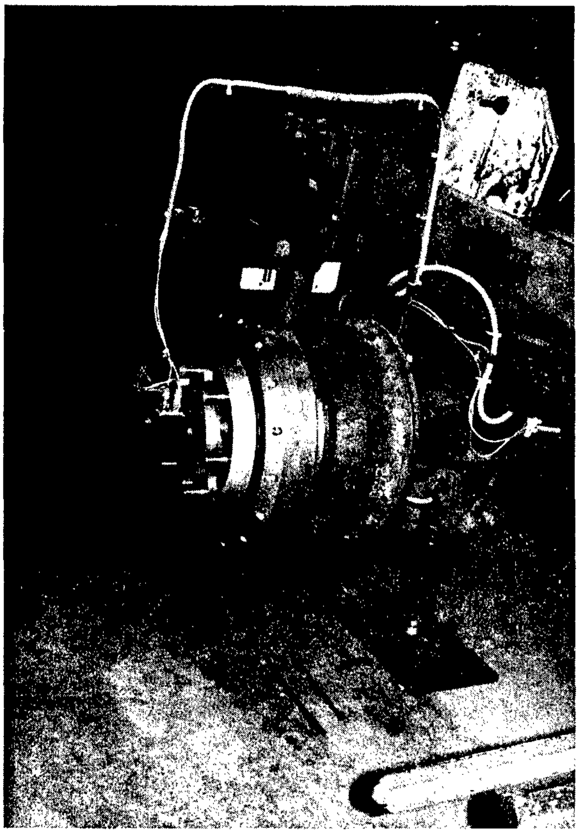


FIGURE 3. TWO-COMPONENT BALANCE

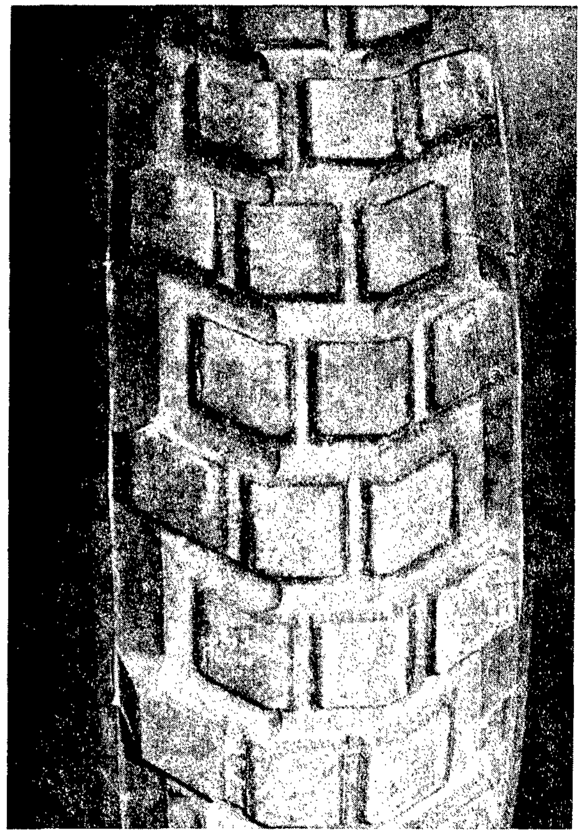


FIGURE 4. TIRE A

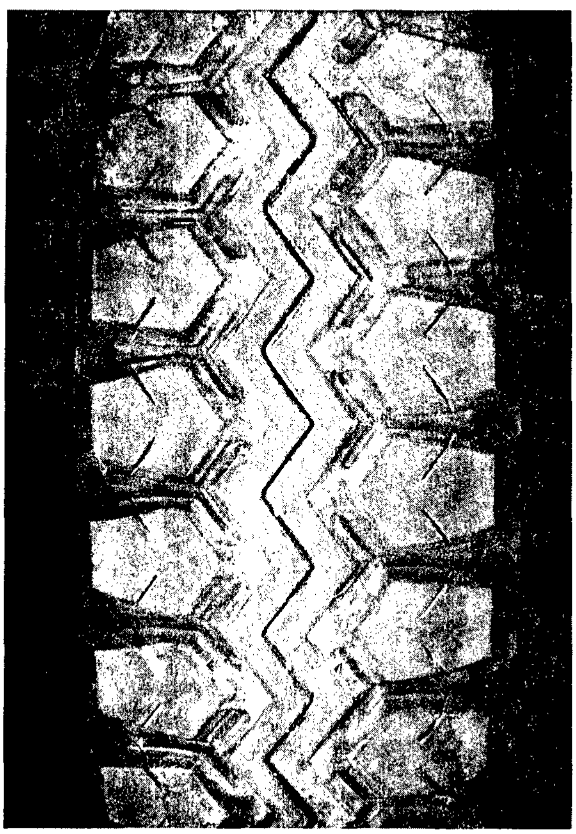


FIGURE 5. TIRE B

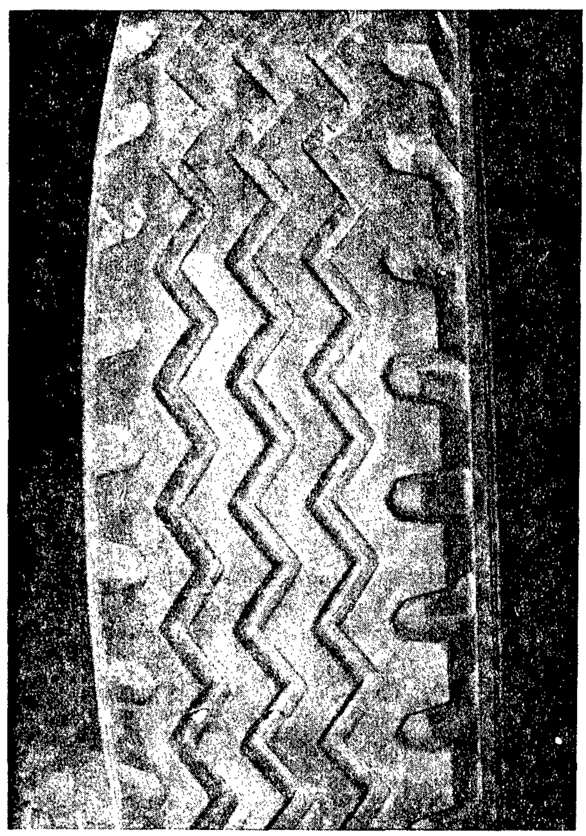


FIGURE 6. TIRE C

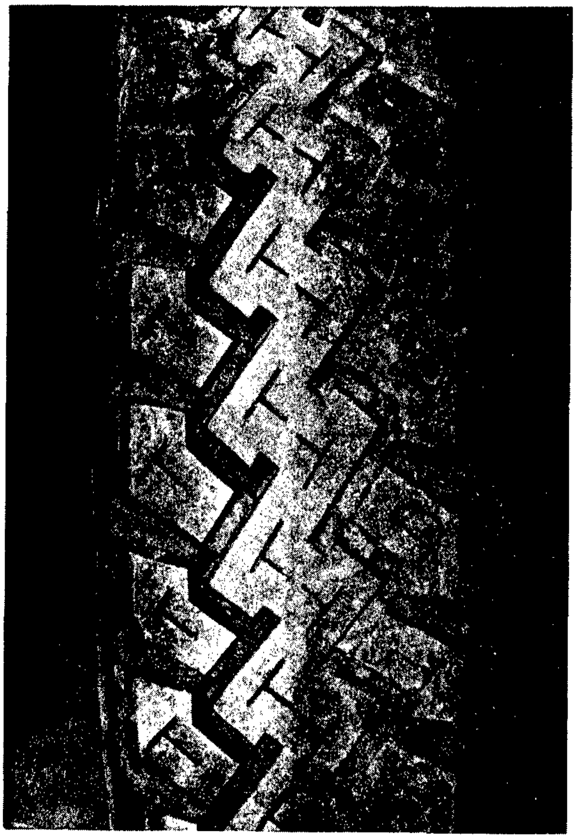


FIGURE 7. TIRE D

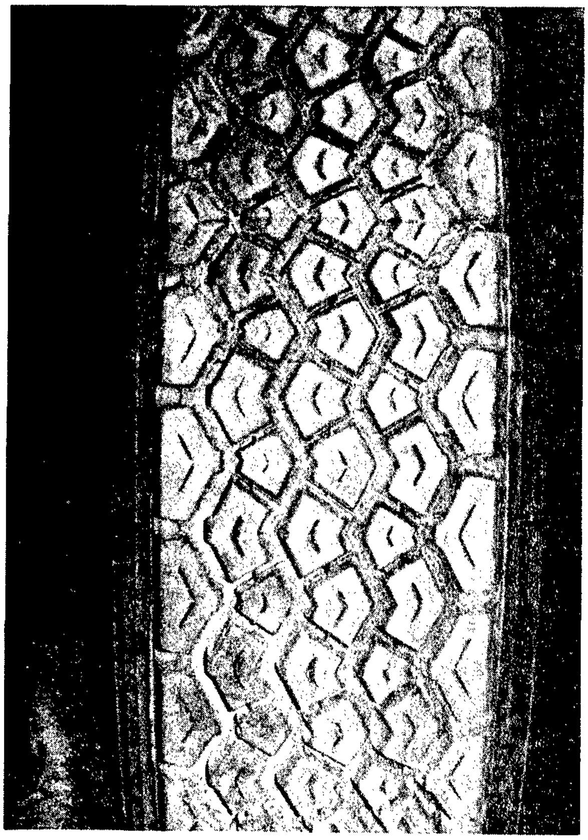


FIGURE 8. TIRE E

FIGURE 9. TIRE F

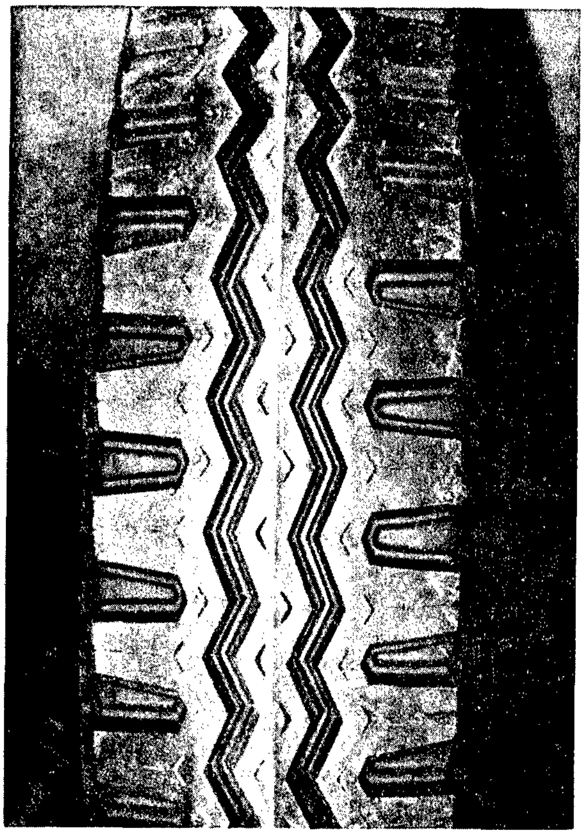


FIGURE 10. TIRE G

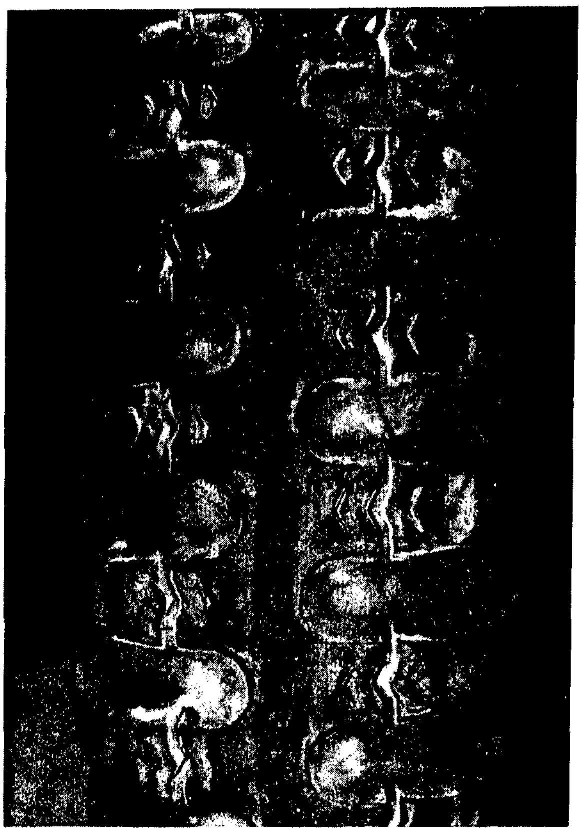


FIGURE 11. TIRE H

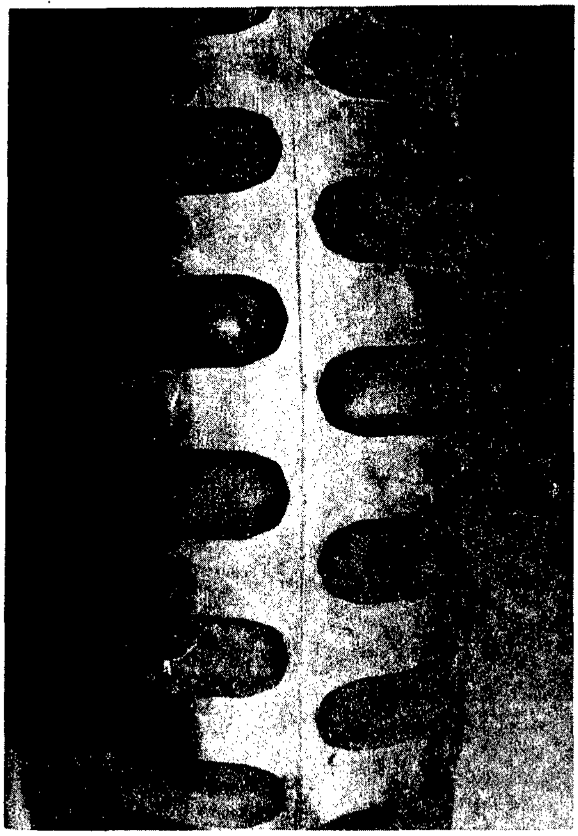


FIGURE 12. TIRE I

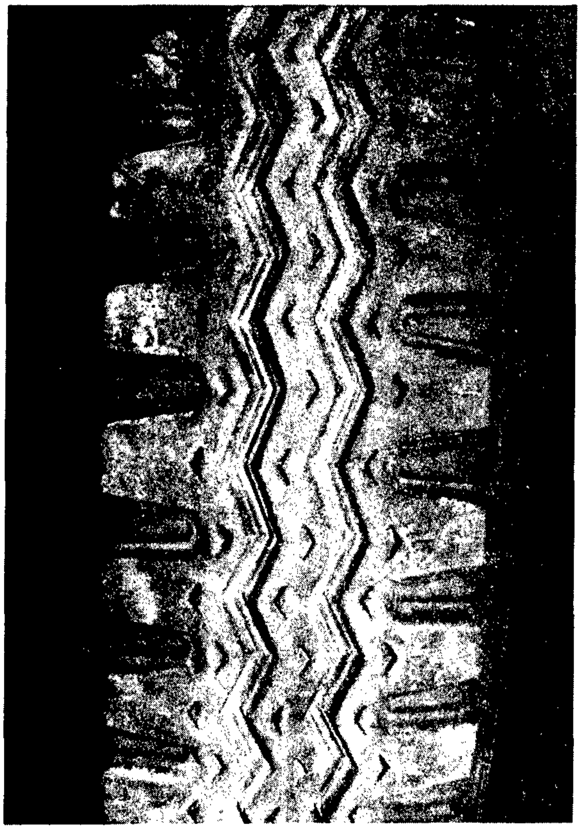


FIGURE 13. TIRE J

All cornering force tests were conducted at 5 mph, at slip angles between plus and minus 10^{o} and at the conditions listed in Table 1.

Table 1

Cornering Force Test Conditions

Load (lb)	Inflation Pressures (psi)
3350	50, 35
2168	50, 35, 15
1504	50, 35, 15

Cornering force tests were conducted under both wet and dry road conditions. Attempts to conduct cornering force tests at the highest load (3350 lb) and lowest pressure (15 psi) yielded erratic results due to the heavily overloaded conditions. They were thus abandoned.

The braking force tests were conducted at the conditions listed in Table 2. All braking tests were conducted wet (0.02 inches of water). Additional tests at other speeds were conducted with the Tire H at 50 psi pressure and both 3350 lb and 2168 lb loads to obtain the relationships between speed and skid number for the road and test conditions employed. Since it is difficult to perform the braking tests at exactly the desired test speed it is necessary to obtain a speed/skid number gradient for the test surface. This gradient (Eq. 3) is then used to correct the actual test data to the nominal speed for comparison purposes.

The road used for all tests was resurfaced in 1972; hence it is considered to be in excellent condition, smooth, with little wear and possessing good traction characteristics. It has an ASTM Skid Number of 55.

Table 2

Braking Force Test Conditions

Load (lb)	Inflation Pressure (psi)	Nominal Speed (mph)
3350	50	30
2168	50	30
2168	35	20
2168	15	10
1504	35	20
1504	15	10

TEST RESULTS

Summaries of all test results are presented in Tables 3 to 12. The loaded radius and tire foot print was recorded for each tire and each load inflation condition.

Data Processing

Braking Force was calculated by Equation (1):

$$BF = \frac{T}{LR} \tag{1}$$

where BF = Braking Force

T = Measured torque at full lock-up (100% skid)

LR = The measured loaded radius (spindle height above level ground) for the load and inflation pressure under study

Skid Number was calculated by Equation (2):

$$SN = \frac{BF}{W - \frac{H}{\ell} BF} \times 100 \tag{2}$$

where SN = Skid Number

BF = Braking force from Equation (1)

Table 3

Tire A

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	29.5	1287	39.7	39.0	28.0	4.7	1702	360	2100	1850	12
		28.7	1325	40.9	39.2	28.0	10.0	1929				
		27.3	1287	39.7	36.1	27.0	7.5	1891				
				Ave.	38.1							
	35								375	1900	1900	0
2168	50	30.6	936	44.9	45.7	28.7	4.6	1085	300	1625	1400	14
		29.0	974	46.7	45.4	28.0	9.5	1422				
		30.0	974	46.7	46.7	29.3	9.0	1310				
				Ave.	45.9							
	35	19.3	1111	53.6	52.7	18.7	6.4	1222	275	1600	1500	6
		18.3	1037	49.9	47.6	19.3	8.6	1274				
		17.3	1185	57.3	53.7	17.0	6.7	1259				
		19.3	1111	53.6	52.7	19.8	8.7	1185				
		19.3	1185	57.3	56.4	-	-	-				
				Ave.	52.6							
	15	9.2	1411	68.9	67.8	9.4	5.3	1533	250	1350	1350	0
		9.4	1490	73.0	72.2	9.2	7.5	1494				
		10.0	1333	64.9	64.9	-	-	-				
		10.1	1411	68.9	71.1	9.5	7.9	1505				
		9.5	1490	73.0	72.3							
				Ave.	69.7							

Table 3 (Cont'd)

Tire A

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	50								200	1150	1000	13
	35	18.0	803	56.0	53.3	19.3	6.9	1038	250	1200	1050	12
		19.3	839	58.6	57.7	19.3	11.0	1076				
		19.3	802	55.9	55.0	20.3	6.5	1000				
		20.0	766	53.2	53.2	19.9	12.0	1077				
				Ave.	54.8							
	15	9.7	948	66.6	66.2	10.4	2.4	951	235	1075	1000	7
		9.7	834	58.2	57.8	10.5	4.7	989				
		9.7	986	69.5	69.1	9.7	3.8	1011				
		10.0	910	63.8	63.8	10.2	1.2	989				
				Ave.	64.2							

Table 4

Tire B

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	30.0	1434	44.4	44.4	28.6	9.2	2118	420	2325	2150	8
		28.0	1510	46.9	44.2	27.3	4.8	1778				
		28.2	1510	46.9	44.5	27.3	7.5	1891				
				Ave.	44.4							
	35								277	2200	2000	9
2168	50	28.0	1039	50.0	47.3	28.0	8.1	1333	320	1700	1550	8
		28.0	965	46.3	43.6	28.0	10.0	1407				
		32.0	779	37.0	39.7	28.0	4.0	1296				
				Ave.	43.5							
	35	18.0	1070	51.5	48.8	18.3	7.2	1473	367	1650	1575	4
		18.6	959	46.0	44.1	18.5	7.2	1326				
		18.0	1033	49.7	47.0	17.3	5.7	1326				
		19.3	1070	51.5	50.6							
				Ave.	47.6							
	15	8.7	1309	63.7	62.0	9.2	5.4	1423	267	1400	1375	2
		10.0	1078	52.0	52.0	9.6	3.8	1538				
		9.7	1155	55.8	55.4	9.6	5.1	1538				
				Ave.	56.5							
1504	50								250	1275	1050	18
	35	18.7	907	63.6	61.9	19.1	6.7	943	300	1300	1150	12
		18.9	871	60.9	59.4	19.3	5.8	943				
		19.0	907	63.6	62.3	19.7	8.4	1051				
		20.0	871	60.9	60.9	20.7	8.0	979				
				Ave.	61.1							

Table 4 (Cont'd)

Tire B

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	10.4	865	60.5	61.0	10.0	5.0	1053	260	1100	1050	4
		10.0	865	60.5	60.5	10.2	4.8	1053				
		10.0	902	63.2	63.2	10.2	4.8	1053				
		9.4	902	63.2	62.4							
				Ave.	61.8							

Table 5

Tire C

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	$L_{\bar{5}}$ (%)
3350	50	27.3	1536	47.7	44.1	26.0	12.8	2154	400	2425	2100	14
		28.0	1689	52.7	50.0	26.0	5.0	2077				
		27.3	1653	51.5	47.9	26.0	4.1	2077				
				Ave.	47.3							
	35								367	2300	2100	8
2168	50	29.3	973	46.7	45.8	29.3	6.8	1460	366	1650	1575	4
		30.6	1011	48.6	49.4	29.3	2.2	1160				
		29.3	1011	48.6	47.7	29.6	4.5	1310				
				Ave.	47.6							
	35	19.3	1283	62.3	61.4	18.0	3.7	1475	350	1650	1600	9
		16.7	1283	62.3	57.9	18.7	5.3	1437				
		18.3	1207	58.5	56.2	18.3	4.3	1594				
		17.7	1320	64.2	61.1	19.0	5.2	1437				
				Ave.	59.1							
	15	9.7	1670	82.5	82.1	-	-	-	233	1400	1400	0
		9.7	1590	78.3	77.9	10.0	3.7	1590				
		9.6	1750	86.7	86.2	-	-	-				
		9.9	1630	80.4	80.3	9.6	2.6	1670				
				Ave.	81.6							
1504	50								200	1275	1200	6
	35	18.6	808	56.3	54.4	18.7	4.2	847	267	1300	1200	8
		18.3	881	61.6	59.3	18.0	4.4	1031				
		20.0	844	58.9	58.9	18.7	10.0	1105				
		18.7	881	61.6	59.9	-	-	-				
				Ave.	58.1							

Table 5 (Cont'd)

Tire C

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	10.0	1031	72.8	72.8	9.8	2.5	1032	250	1200	1150	4
		9.6	1184	84.4	83.9	-	-	-				
		9.9	993	70.0	69.9	9.7	3.8	1055				
		9.0	916	64.2	62.9	9.9	6.3	1124				
				Ave.	72.4							

Table 6

Tire D

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	29.3	1401	43.4	42.5	28.7	5.0	1703	440	2300	2250	2
		29.3	1401	43.4	42.5	27.7	7.2	1831				
		28.0	1476	45.8	43.1	28.9	6.0	1778				
				Ave.	42.7							
	35								435	2450	2200	10
2168	50	29.3	967	46.4	45.5	29.3	9.0	1191	355	1850	1600	14
		29.7	893	42.7	42.3	28.7	7.0	1117				
		30.0	930	44.5	44.5	28.7	5.6	1080				
				Ave.	44.1							
	35	17.0	1143	55.3	51.3	19.3	4.1	1368	400	1725	1400	19
		19.3	1254	60.9	60.0	17.3	5.7	1400				
		18.7	1180	57.1	55.4	19.3	5.8	1326				
		18.3	1254	60.9	58.6	-	-	-				
				Ave.	56.3							
	15	10.0	1372	66.9	69.9	8.9	2.8	1573	300	1550	1450	6
		9.5	1411	68.9	68.2	9.2	2.7	1494				
		9.0	1490	73.0	74.3	9.5	2.6	1533				
		8.7	1725	85.4	83.7	-	-	-				
				Ave.	74.0							
1504	50								267	1325	1100	17
	35	19.3	880	61.6	60.7	-	-	-	375	1300	1100	15
		20.0	880	61.6	61.6	20.3	6.5	884				
		20.0	880	61.6	61.6	17.7	9.4	957				
		17.7	880	61.6	58.5	18.7	10.7	994				
				Ave.	60.6							

Table 6 (Cont'd)

Tire D

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	10.0	1063	75.2	75.2	10.2	2.5	1065	300	1150	1075	6
		10.0	1063	75.2	75.2	10.2	1.0	1065				
		10.6	1025	72.4	73.2	9.8	5.0	1065				
		10.0	1063	75.2	75.2	-	-	-				
				Ave.	74.7							

Table 7

Tire E

Conditions: Load (lb)	Conditions: Infl. Press. (psi)	Full Skid: Speed (mph)	Full Skid: B'king Force (lb)	Full Skid: Skid No.	Full Skid: Adj. Skid No.	Peak Braking: Speed (mph)	Peak Braking: Skid (%)	Peak Braking: B'king Force (lb)	Cornering Force: Coeff. (#/°)	Cornering Force: Dry @10° (lb)	Cornering Force: Wet @10° (lb)	Cornering Force: L_5 (%)
3350	50	26.0	1541	47.9	42.5	26.6	5.1	1844	400	2250	2100	6
		25.3	1466	45.5	39.2	27.3	10.0	1919				
		29.3	1428	44.2	43.3	26.0	7.6	1618				
		29.3	1505	46.7	45.8	28.6	7.0	1919				
				Ave.	42.7							
	35								350	1950	1850	5
2168	50	30.0	1035	49.8	49.8	29.6	10.0	1333	350	1550	1450	6
		30.0	888	42.4	42.4	34.0	6.6	1259				
		29.3	888	42.4	41.5	26.7	7.5	1370				
				Ave.	44.6							
	35	18.6	1058	51.0	49.1	17.5	6.5	1332	325	1400	1325	5
		18.6	983	47.0	46.5	17.5	5.3	1211				
		18.6	1058	51.0	50.5	18.0	18.5	1453				
				Ave.	48.7							
	15	10.2	1467	71.8	72.1	8.0	7.2	1670	245	1250	1200	4
		10.3	1428	69.8	70.2	10.1	3.7	1511				
		10.0	1348	65.7	65.7	10.1	6.2	1591				
				Ave.	69.3							
1504	50								250	1100	1100	0
	35	18.0	675	46.7	44.0	19.3	3.4	753	275	1175	1100	6
		19.0	675	46.7	45.4	18.0	1.8	715				
		17.6	675	46.7	43.5	18.0	10.0	978				
				Ave.	44.3							
	15	9.7	938	65.8	65.4	8.7	5.1	1017	300	1025	950	8
		8.6	938	65.8	63.7	9.2	1.3	821				
		8.7	938	65.8	64.1	8.8	11.4	1095				
				Ave.	64.4							

Table 8

Tire F

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry_o @10° (lb)	Wet_o @10° (lb)	L_5 (%)
3350	50	29.3	1313	40.5	39.6	28.0	5.0	1693	325	2075	2075	0
		28.6	1388	42.9	41.0	28.0	10.0	1806				
		29.3	1313	40.5	39.6	28.6	11.0	1844				
				Ave.	40.1							
	35								267	1825	1850	0
2168	50	30.0	816	38.8	38.8	30.3	4.4	1222	325	1625	1550	5
		29.3	853	40.7	39.8	29.3	13.0	1148				
		30.7	963	46.2	47.1	28.0	9.5	1311				
				Ave.	41.9							
	35	18.6	1209	58.5	56.6	20.1	3.3	1210	300	1475	1400	5
		18.3	1209	58.5	56.2	18.3	4.3	1324				
		19.3	1171	56.6	55.7	18.7	3.5	1362				
				Ave.	56.2							
	15	8.5	1496	73.3	71.3	9.1	11.0	1496	192	1200	1150	4
		9.7	1378	67.2	66.8	10.7	7.6	1378				
		10.0	1338	65.0	65.0	10.4	3.6	1338				
		10.0	1457	71.3	71.3	-	-	-				
				Ave.	68.6							
1504	50								275	1175	1175	0
	35	18.6	887	62.1	60.2	18.7	4.3	888	250	1200	1150	4
		19.0	850	59.4	58.1	20.0	9.0	925				
		18.0	887	62.1	59.4	20.0	5.0	977				
				Ave.	59.2							

Table 8 (Cont'd)

Tire F

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	9.4	987	69.5	68.7	-	-	-	200	975	950	2
		9.4	1063	75.2	74.4	-	-	-				
		9.5	1025	72.4	71.7	9.3	8.6	1103				
		9.2	1101	78.1	77.0	-	-	-				
				Ave.	73.0							

Table 9

Tire G

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	30	1753	56	56	None Recorded			398	2440	2420	1
			1838	59	59							
				Ave.	57.5							
		20	1838	59	59							
			2107	68.5	68.5							
			1979	64	64							
				Ave.	63.8							
		10	2036	66	66							
			2086	68	68							
			1994	64.5	64.5							
			2079	67.5	67.5							
				Ave.	66.5							
	35	30	1518	48	48				368	2210	2130	4
			1482	47	47							
				Ave.	47.5							
		20	1865	60	60							
			1966	63.5	63.5							
			1807	58	58							
			1908	61.5	61.5							
				Ave.	60.8							
		10	2168	70.5	70.5							
			2132	69	69							
			2082	67.5	67.5							
			2241	73	73							
				Ave.	70							

Table 9 (Cont'd)

Tire G

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
2168	50	30	1107	54.5	54.5	None Recorded			288	1690	1670	1
			1162	57.5	57.3							
			1072	53.0	53.0							
				Ave.	55.0							
		20	1211	60	60							
			1259	63	63							
			1266	63	63							
				Ave.	62.0							
		10	1453	73.5	73.5							
			1418	71.5	71.5							
			1453	73.5	73.5							
				Ave.	72.8							
	35	30	1119	55.5	55.5				310	1690	1680	1
			1105	54.5	54.5							
			1105	54.5	54.5							
				Ave.	54.8							
		20	1174	58	58							
			1153	57	57							
			1223	61	61							
				Ave.	58.7							
		10	1398	70.5	70.5							
			1398	70.5	70.5							
			1524	78	78							
			1468	74	74							
				Ave.	73.2							

Table 9 (Cont'd)

Tire G

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
2168	15	30	1221	62	62	None Recorded			257	1490	1470	1
			1221	62	62							
			1294	65	65							
			1236	61.5	61.5							
				Ave.	62.6							
		20	1272	63.5	63.5							
			1309	65.5	65.5							
			1323	66.5	66.5							
				Ave.	65.0							
		10	1483	75	75							
			1636	84	84							
			1636	84	84							
				Ave.	81.0							
1504	35	30	773	56	56				267	1350	1260	6
			745	53	53							
			756	54	54							
				Ave.	54.5							
		20	884	64	64							
			884	64	64							
				Ave.	64.0							
		10	1105	81.5	81.5							
			1174	87.5	87.5							
			1118	83	83							
				Ave.	84.0							

Table 9 (Cont'd)

Tire G

Conditions: Load (lb)	Conditions: Infl. Press. (psi)	Full Skid: Speed (mph)	Full Skid: B'king Force (lb)	Full Skid: Skid No.	Full Skid: Adj. Skid No.	Peak Braking: Speed (mph)	Peak Braking: Skid (%)	Peak Braking: B'king Force (lb)	Cornering Force: Coeff. (#/°)	Cornering Force: Dry @10° (lb)	Cornering Force: Wet @10° (lb)	Cornering Force: L_5 (%)
1504	15	30	852	61.5	61.5	None Recorded			248	1210	1210	0
			852	61.5	61.5							
			902	65.5	65.5							
				Ave.	64.5							
		20	888	64	64							
			1065	78	78							
			923	67	67							
				Ave.	69.7							
		10	1136	84	84							
			1108	81.5	81.5							
			1101	81	81							
				Ave.	82.0							

Table 10

Tire H

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	29.3	1289	39.8	38.9	28.0	9.75	1768	340	2300	2200	4
		31.6	1215	37.4	39.5	-	-	-				
		28.5	1289	39.8	37.8	-	-	-				
		19.0	1989	62.5								
		20.3	1768	55.2								
		9.0	2136	67.4								
		8.7	2136	67.4								
		26.0	1473									
				Ave.	38.7							
	35								350	2250	2050	9
2168	50	35.0	806	38.4	45.1				285	1700	1500	12
		34.1	586	27.7	33.2							
		30.6	770	36.6	37.4							
		24.5	858	41.0								
		25.2	858	41.0								
		21.4	1004	48.2								
		19.4	1063	51.2								
		17.7	1063	51.2								
		15.7	1173	56.7								
		16.4	1209	58.6								
		11.2	1319	64.2								
				Ave.	38.6							
	35	19.0	1183	57.2	55.9	18.3	7.2	1333	340	1700	1550	8
		19.3	1220	59.1	60.0	19.7	6.7	1444				
		16.7	1220	59.1	54.1	-	-	-				
		18.7	1333	64.9	63.2	-	-	-				
				Ave.	58.3							

Table 10(Cont'd)

Tire H

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
2168	15	10.0	1463	71.6	71.6	-	-	-	250	1800	1500	16
		10.2	1463	71.6	71.9	10.2	7.3	1538				
		9.5	1463	71.6	70.9	-	-	-				
		9.9	1463	71.6	71.5							
				Ave.	71.5							
1504	50								215	1225	1125	8
	35	19.1	797	55.5	54.3	19.0	7.0	907	225	1250	1100	12
		19.0	869	60.8	59.5	-	-	-				
		19.0	797	55.5	54.2	-	-	-				
		19.0	833	58.1	56.5	-	-	-				
				Ave.	56.1							
	15	10.0	1043	73.7	73.7	9.7	7.6	1043	225	1225	1175	4
		10.7	1118	79.4	80.3	-	-	-				
		10.2	1043	73.7	74.0	-	-	-				
		9.6	1043	73.7	73.2	-	-	-				
				Ave.	75.3							

Table 11

Tire 1

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	30	1729	53.8	53.8	None Recorded			348	2220	2210	1
			1588	49.2	49.2							
			1609	49.8	49.8							
				Ave.	50.9							
		20	1927	60.3	60.3							
			1835	57.3	57.3							
			1892	59.2	59.2							
				Ave.	58.9							
		10	2315	73.0	73.0							
			2259	71.3	71.3							
			2259	71.3	71.3							
				Ave.	71.9							
	35	30	1672	52.0	52.0				297	2120	1980	4
			1763	54.9	54.9							
				Ave.	53.4							
		20	1994	62.5	62.5							
			2018	63.3	63.3							
			1874	58.6	58.6							
				Ave.	61.5							
		10	2278	71.9	71.9							
			2278	71.9	71.9							
			2307	72.9	72.9							
				Ave.	72.2							

Table 11 (Cont'd)

Tire 1

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
2168	50	30	1038	49.8	49.8	None Recorded			308	1800	1760	2
			1012	48.5	48.5							
			934	44.6	44.6							
				Ave.	47.6							
		20	1157	55.7	55.7							
			1207	58.3	58.3							
			1285	62.2	62.2							
				Ave.	58.7							
		10	1427	69.5	69.5							
			1375	66.8	66.8							
			1329	64.5	64.5							
			1531	74.8	74.8							
				Ave.	68.9							
	35	30	1106	53.2	53.2				275	1780	1700	4
			1011	48.4	48.4							
				Ave.	50.8							
		20	1190	57.4	57.4							
			1159	55.8	55.9							
			1222	59.0	59.0							
				Ave.	57.4							
		10	1480	72.2	72.2							
			1527	74.6	74.6							
				Ave.	73.4							

Table 11 (Cont'd)

Tire 1

Conditions: Load (lb)	Conditions: Infl. Press. (psi)	Full Skid: Speed (mph)	Full Skid: B'king Force (lb)	Full Skid: Skid No.	Full Skid: Adj. Skid No.	Peak Braking: Speed (mph)	Peak Braking: Skid (%)	Peak Braking: B'king Force (lb)	Cornering Force: Coeff. (#/°)	Cornering Force: Dry @10° (lb)	Cornering Force: Wet @10° (lb)	L_5 (%)
2168	15	30	1121	53.9	53.9	None Recorded			190	1440	1430	1
			1135	54.6	54.6							
			1245	60.2	60.2							
			1245	60.2	60.2							
				Ave.	57.2							
		20	1301	63.0	63.0							
			1287	62.3	62.3							
				Ave.	62.7							
		10	1439	70.1	70.1							
			1411	68.7	68.7							
			1481	72.3	72.3							
			1530	74.8	74.8							
				Ave.	71.5							
1504	35	30	792	55.1	55.1				253	1360	1270	7
			751	52.2	52.2							
			723	50.1	50.1							
				Ave.	52.5							
		20	846	59.1	59.1							
			853	59.6	59.6							
			860	60.1	60.1							
			887	62.1	62.1							
				Ave.	60.2							
		10	921	64.6	64.6							
			990	69.7	69.7							
			1017	71.7	71.7							
			1003	70.6	70.6							
				Ave.	69.2							

Table 11 (Cont'd)

Tire I

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	30	849	59.3	59.3	None Recorded			222	1270	1150	9
			845	59.0	59.0							
			852	59.5	59.5							
			852	59.5	59.5							
				Ave.	59.3							
		20	909	63.7	63.7							
			909	63.7	63.7							
			849	59.3	59.3							
			1037	73.2	73.2							
				Ave.	65.0							
		10	1023	72.1	72.1							
			1065	75.3	75.3							
			1137	80.7	80.7							
			1136	80.7	80.7							
				Ave.	77.2							

Table 12

Tire J

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
3350	50	30.0	1570	48.8	48.8	26.7	2.5	1909	460	2325	2325	0
		26.6	1570	48.8	44.2	28.7	7.0	2059				
		25.3	1647	51.3	45.0	26.7	7.5	2246				
				Ave.	46.0							
	35								450	2200	2200	0
2168	50	29.3	911	43.6	42.7	29.0	4.6	1495	350	1650	1650	0
		29.3	947	45.4	44.5	30.0	4.4	1422				
		29.3	911	43.6	42.7	29.3	8.2	1458				
				Ave.	43.3							
	35	19.0	1338	65.1	63.8	-	-	-	320	1600	1600	0
		18.6	1338	65.1	63.0	18.7	2.8	1355				
		20.0	1264	61.4	61.4	17.3	6.1	1526				
				Ave.	62.7							
	15	9.5	1688	83.5	82.8	-	-	-	267	1400	1400	0
		10.0	1727	85.5	85.5	8.1	7.8	1808				
		10.0	1649	81.4	81.4	9.2	5.4	1691				
		9.5	1727	85.5	84.8	9.1	8.2	1808				
				Ave.	83.6							
1504	50								245	1250	1250	0
	35	19.3	923	64.8	63.9	18.7	6.4	1259	243	1300	1250	4
		18.6	1034	73.0	71.1	18.8	5.3	1185				
		18.0	1034	73.0	70.2	20.3	4.9	1222				
		18.6	997	70.3	68.4							
				Ave.	68.4							

Tire 12 (Cont'd)

Tire J

Conditions		Full Skid				Peak Braking			Cornering Force			
Load (lb)	Infl. Press. (psi)	Speed (mph)	B'king Force (lb)	Skid No.	Adj. Skid No.	Speed (mph)	Skid (%)	B'king Force (lb)	Coeff. (#/°)	Dry @10° (lb)	Wet @10° (lb)	L_5 (%)
1504	15	9.2	1189	84.8	83.7	9.7	5.1	1230	300	1150	1075	6
		10.0	1228	87.8	87.8	9.5	4.4	1230				
		10.5	1189	84.8	85.5	-	-	-				
				Ave.	85.6							

W = Tire Load

H = Trailer Hitch Height

ℓ = Distance from trailer axle to center of hitch

The Adjusted Skid Number was calculated by Equation (3)

$$ASN = SN - 1.34\ (V_n - V_a) \tag{3}$$

where ASN = Adjusted Skid Number

V_n = The Nominal Test Speed (see Table 2)

SN = The calculated Skid Number from Equation (2)

V_a = The measured test speed in mph

1.34 = The correction factor obtained from the additional Tire H tire tests (see above)

The peak braking force was obtained from the torque trace prior to full lock-up. Since this condition is highly unstable, it is not obtained for all test conditions.* The skid conditions for this peak force, calculated by Equation (4), was also recorded

$$S = \frac{V_a - V_b}{V_a} \tag{4}$$

where S = Skid (expressed in per cent)

V_a = The measured test speed

V_b = The measured speed of the braked wheel

All cornering force measurements were plotted against slip angle (see Appendix). The slope of this curve at zero slip angle, zero camber and zero cornering force is called the "cornering coefficient." The cornering forces measured at plus and minus 10°, where the curve has usually reached its peak, were averaged and used as the performance indicator.

*For tires I and G no attempt at all was made to obtain this peak.

The loss in cornering force due to the wet condition at 5 mph was calculated by Equation (5) and is expressed in the tables as per cent.

$$L_5 = 1 - \frac{WCF}{DCF} \tag{5}$$

where L_5 = The loss in cornering force due to wetness at 5 mph (expressed in per cent)

WCF = The averaged measured cornering force at 10° slip angle under wet conditions

DCF = The average measured cornering force at 10° slip angle under dry conditions

It must be noted that these tests are highly dependent on road surface and water film thickness. It is generally accepted that cornering force does not vary with speed in the dry but that speed is significant in the wet. Thus greater differences than those shown in these tables would be exhibited as the forward speed increases.

To compare performance, the cornering force at 10° (Figures 14 to 23) and the Adjusted Skid Numbers (Figures 24 to 33) for each tire were plotted for each condition tested. Straight lines were then drawn between the plotted points as a visual aid for comparison. The figures are presented in descending order of overall performance in the opinion of the authors. (For example, the tire plotted in Figure 14 is deemed superior in cornering characteristics to that in Figure 15; likewise, that in Figure 24 is superior in braking to that in Figure 25). Performance at high load was weighted over that at low load, at high speed over that at low speed; and under wet conditions over that under dry.

From these figures, it appears that the top four tires are Tires G, J, C and D. Tire F appears to be the worst; while the others are somewhere in the middle, some performing better in braking and others better in cornering. Of interest, Tire I, the standard Army NDCC tread performs about equally to Tire H, the NDCC tread with a few added grooves. Likewise, Tires G and J, with the same tread pattern, but different carcasses performed about equally.

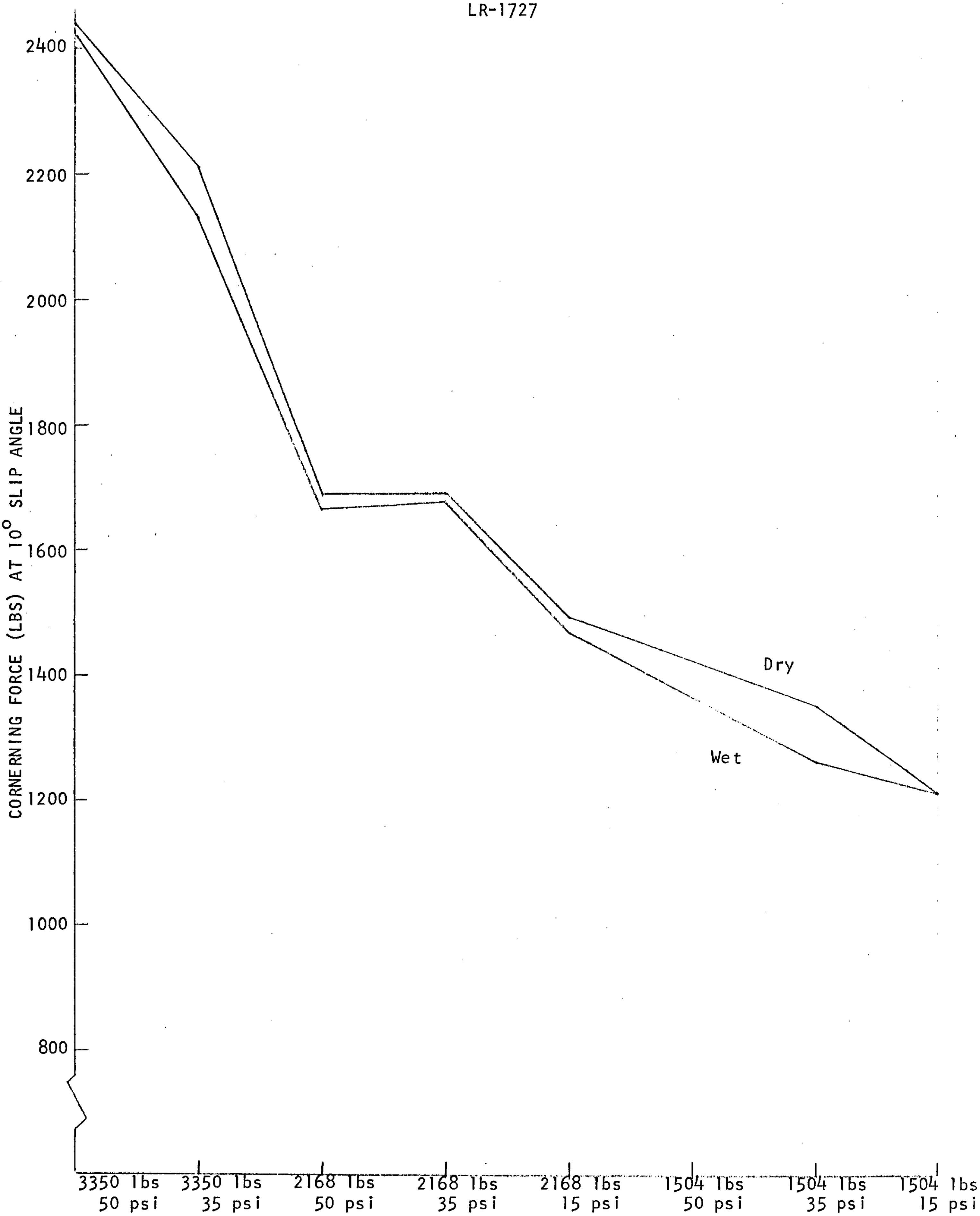


FIGURE 14. CORNERING FORCE PERFORMANCE OF TIRE G

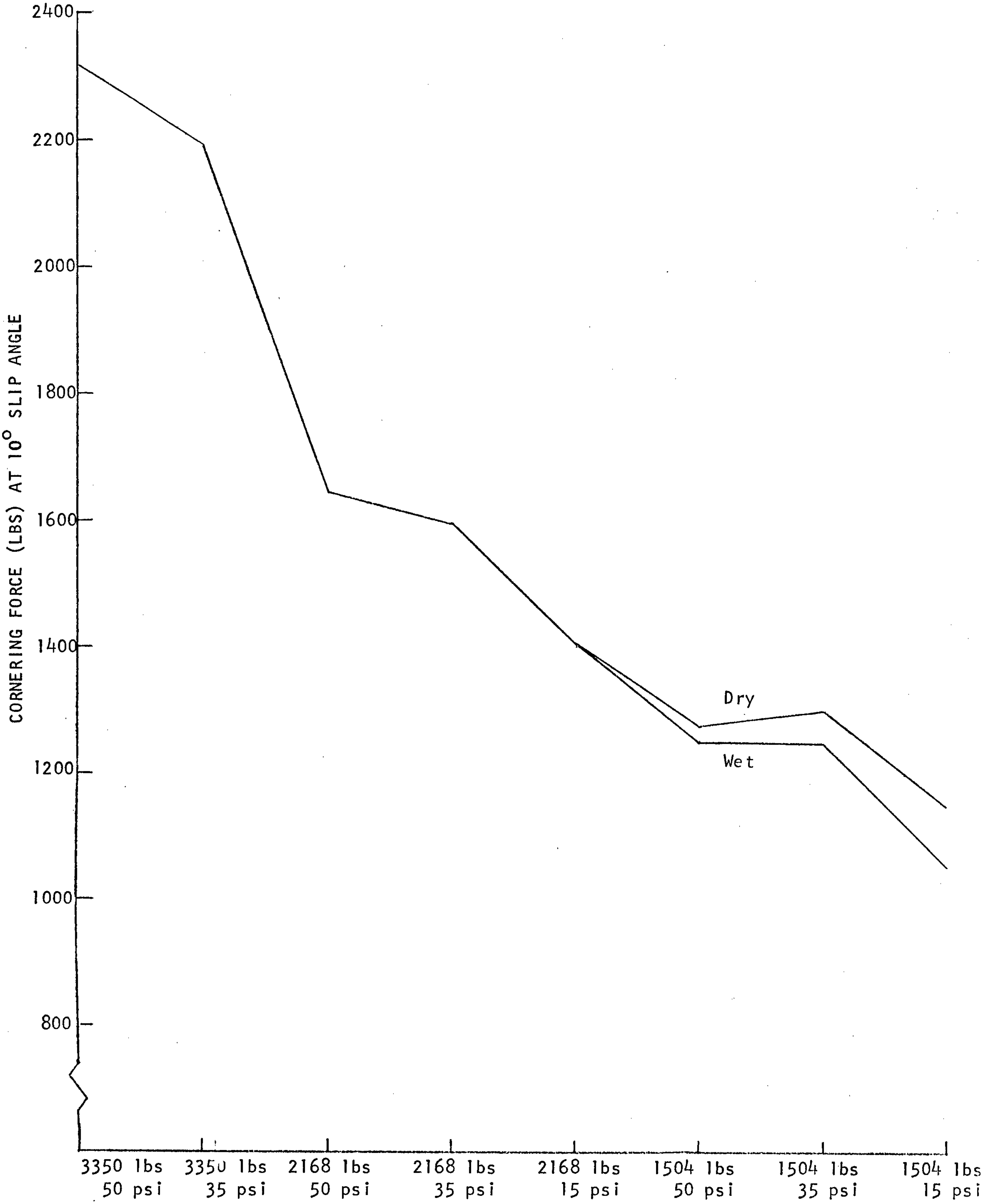


FIGURE 15. CORNERING FORCE PERFORMANCE OF TIRE J

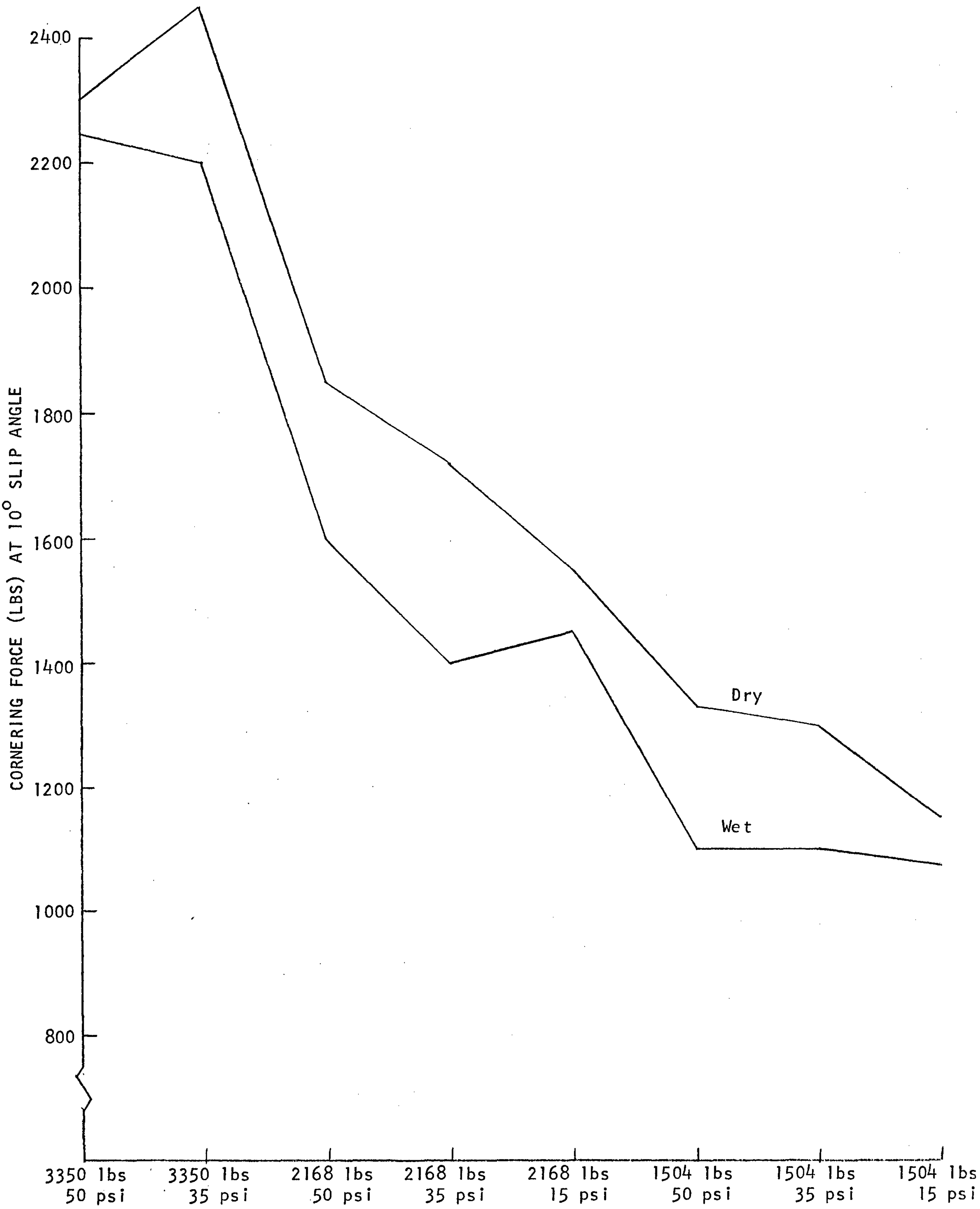


FIGURE 16. CORNERING FORCE PERFORMANCE OF TIRE D

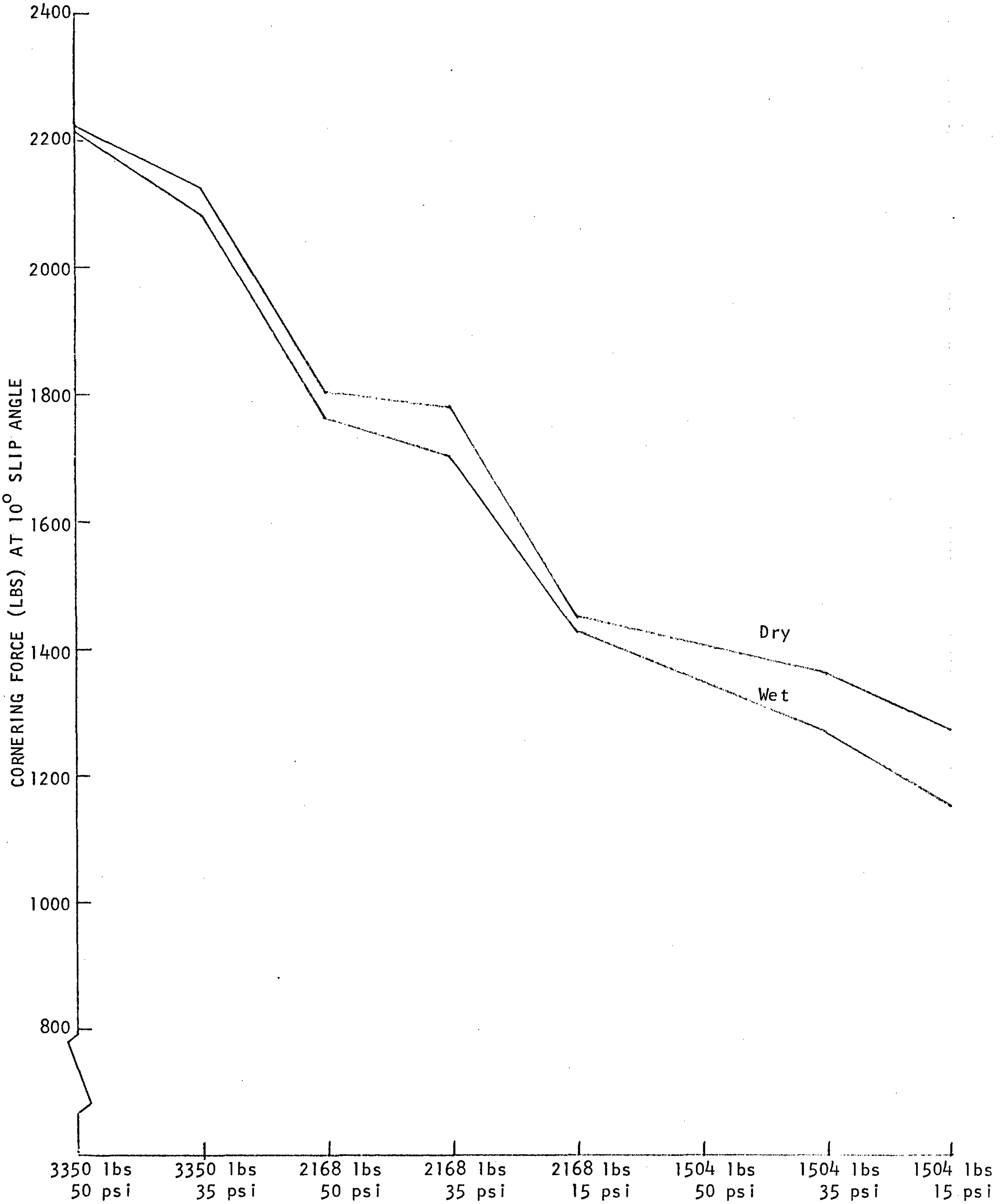


FIGURE 17. CORNERING FORCE PERFORMANCE OF TIRE I

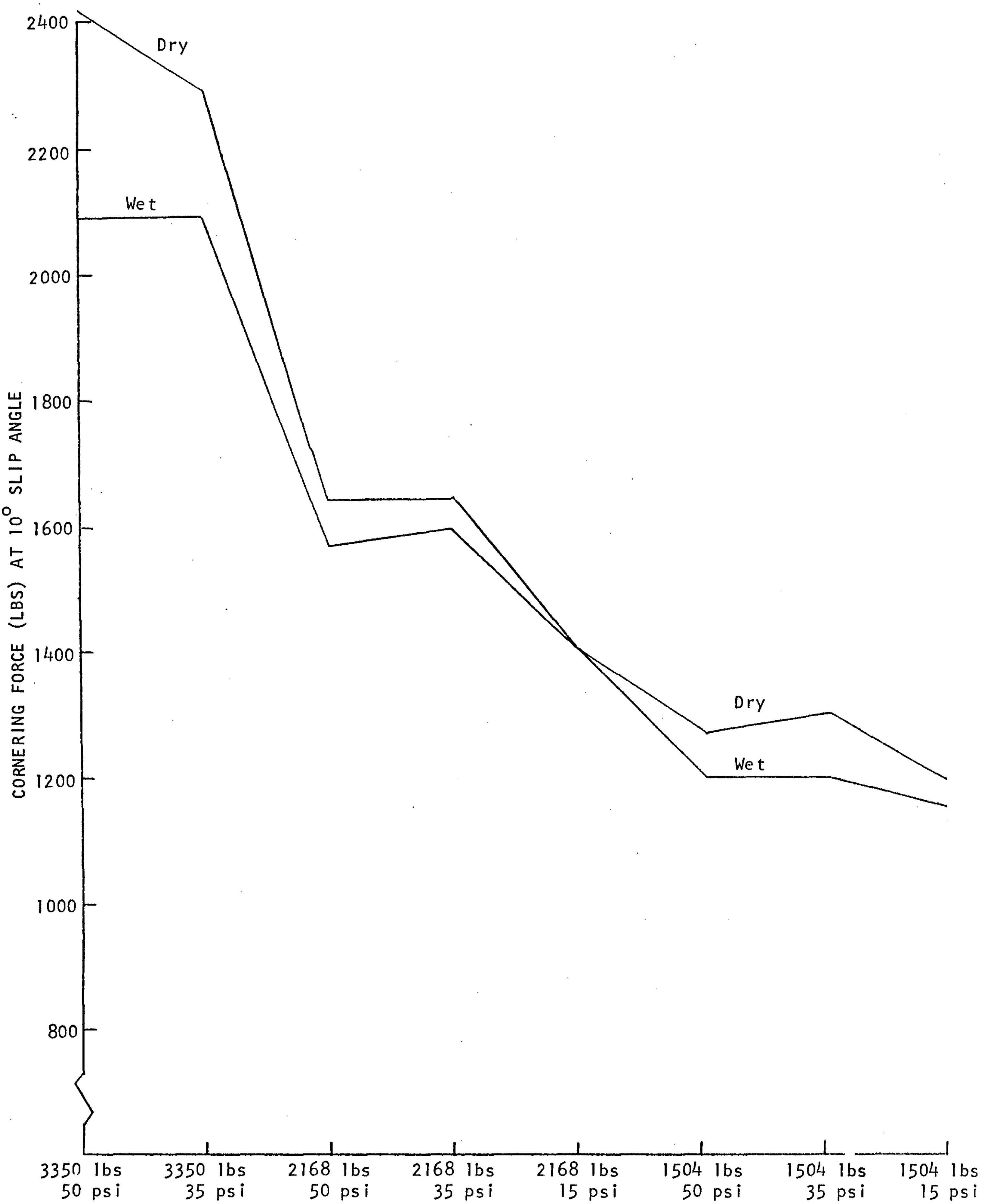


FIGURE 18. CORNERING FORCE PERFORMANCE OF TIRE C

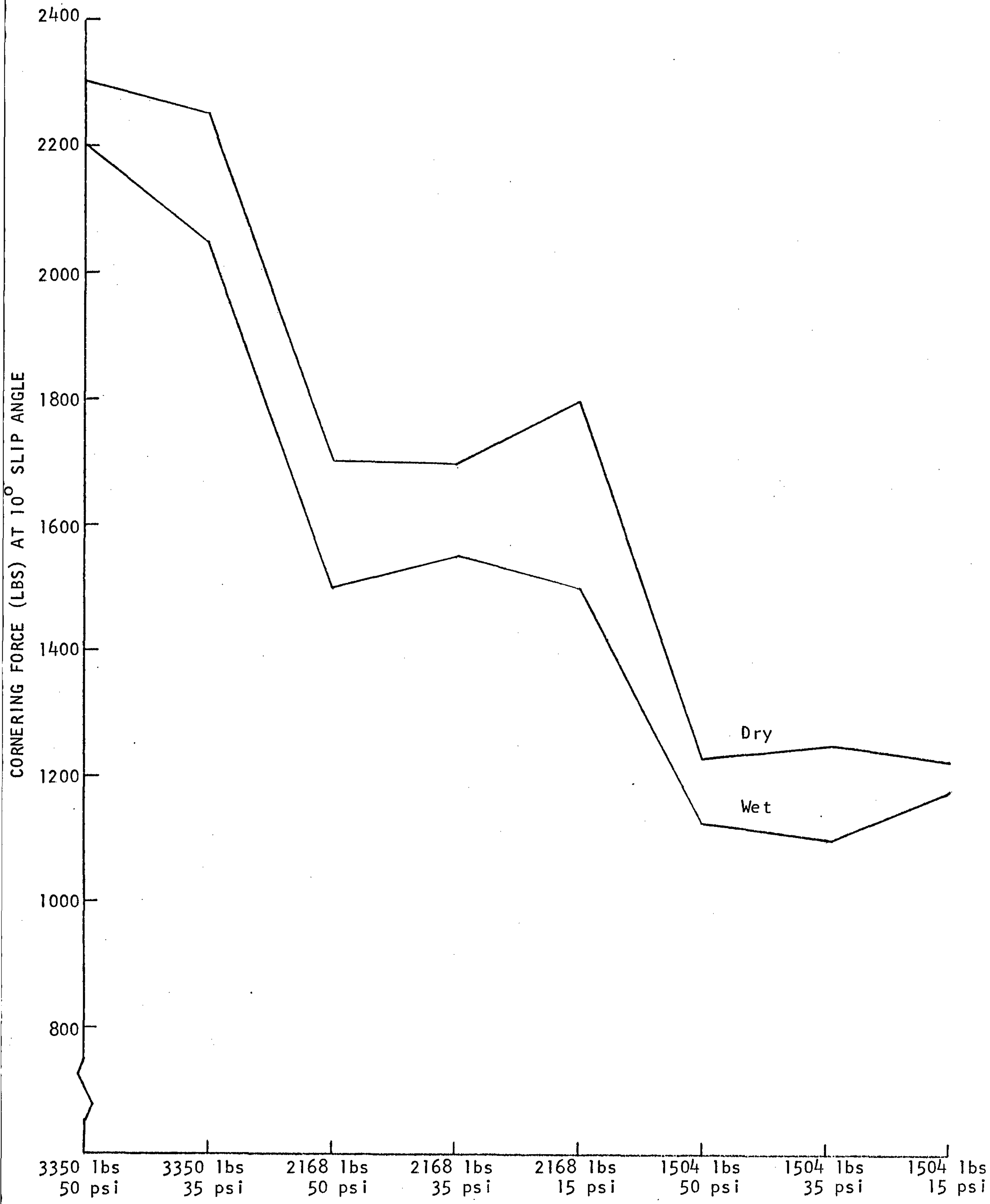


FIGURE 19. CORNERING FORCE PERFORMANCE OF TIRE H

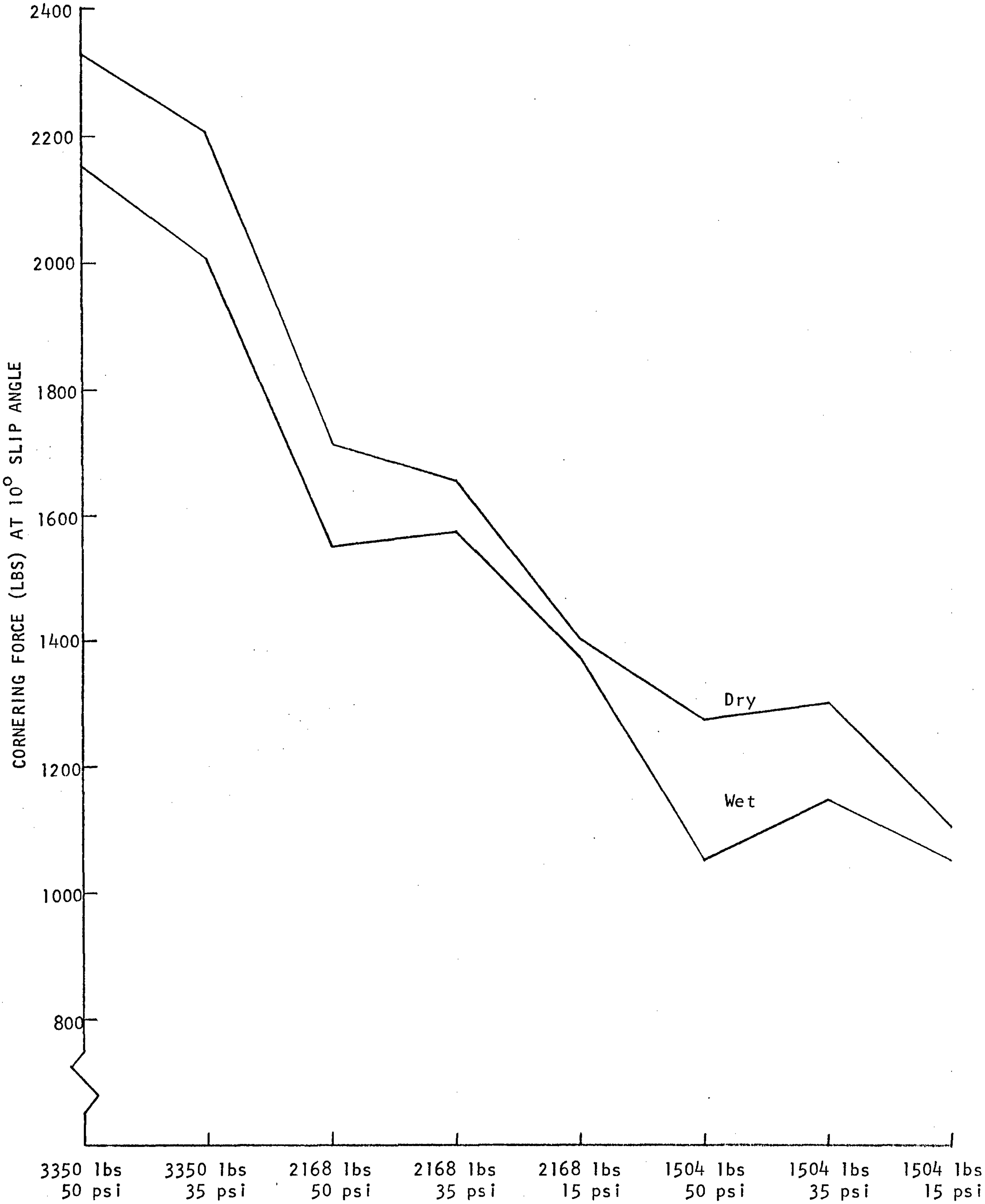


FIGURE 20. CORNERING FORCE PERFORMANCE OF TIRE B

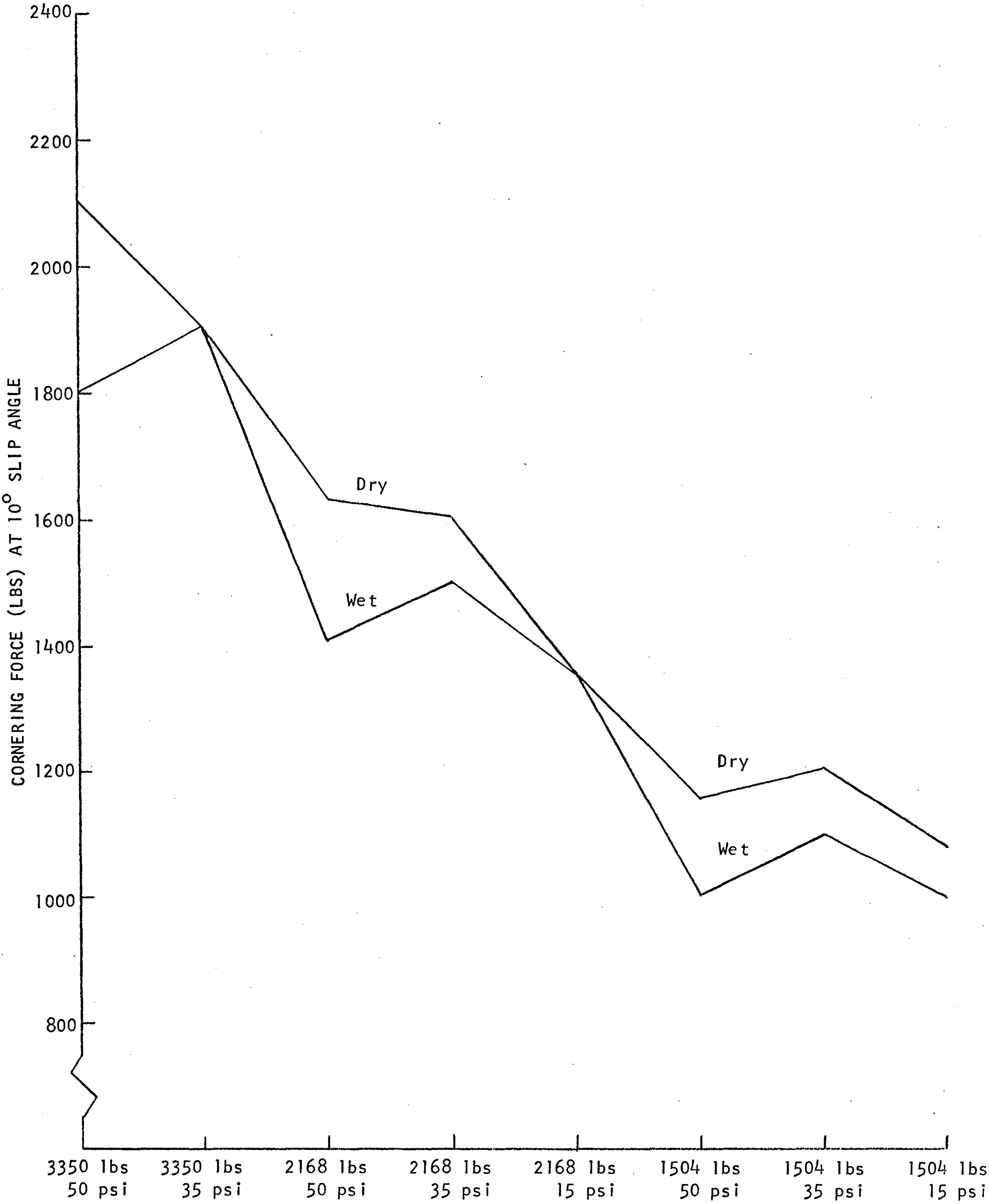


FIGURE 21. CORNERING FORCE PERFORMANCE OF TIRE A

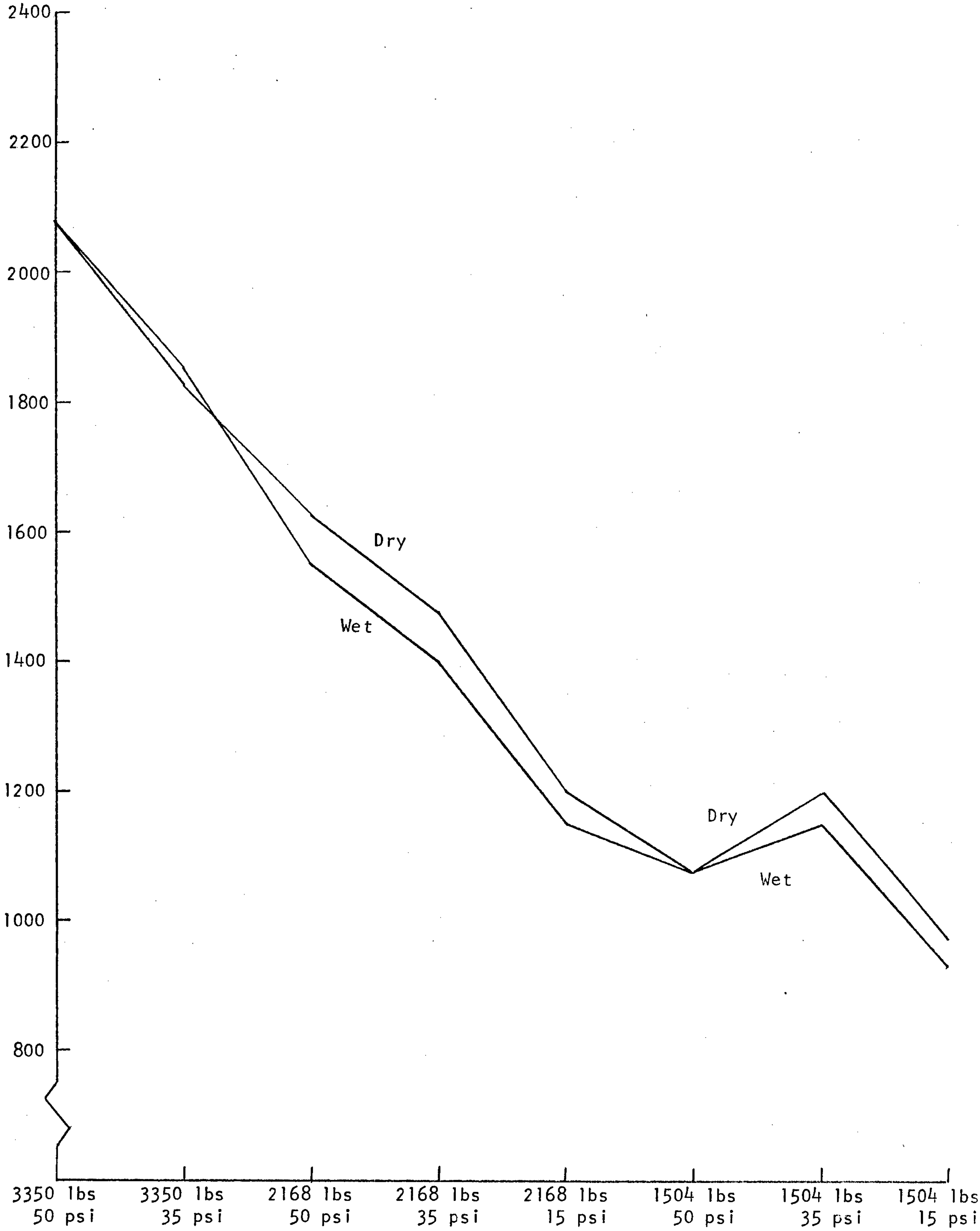


FIGURE 22. CORNERING FORCE PERFORMANCE OF TIRE F

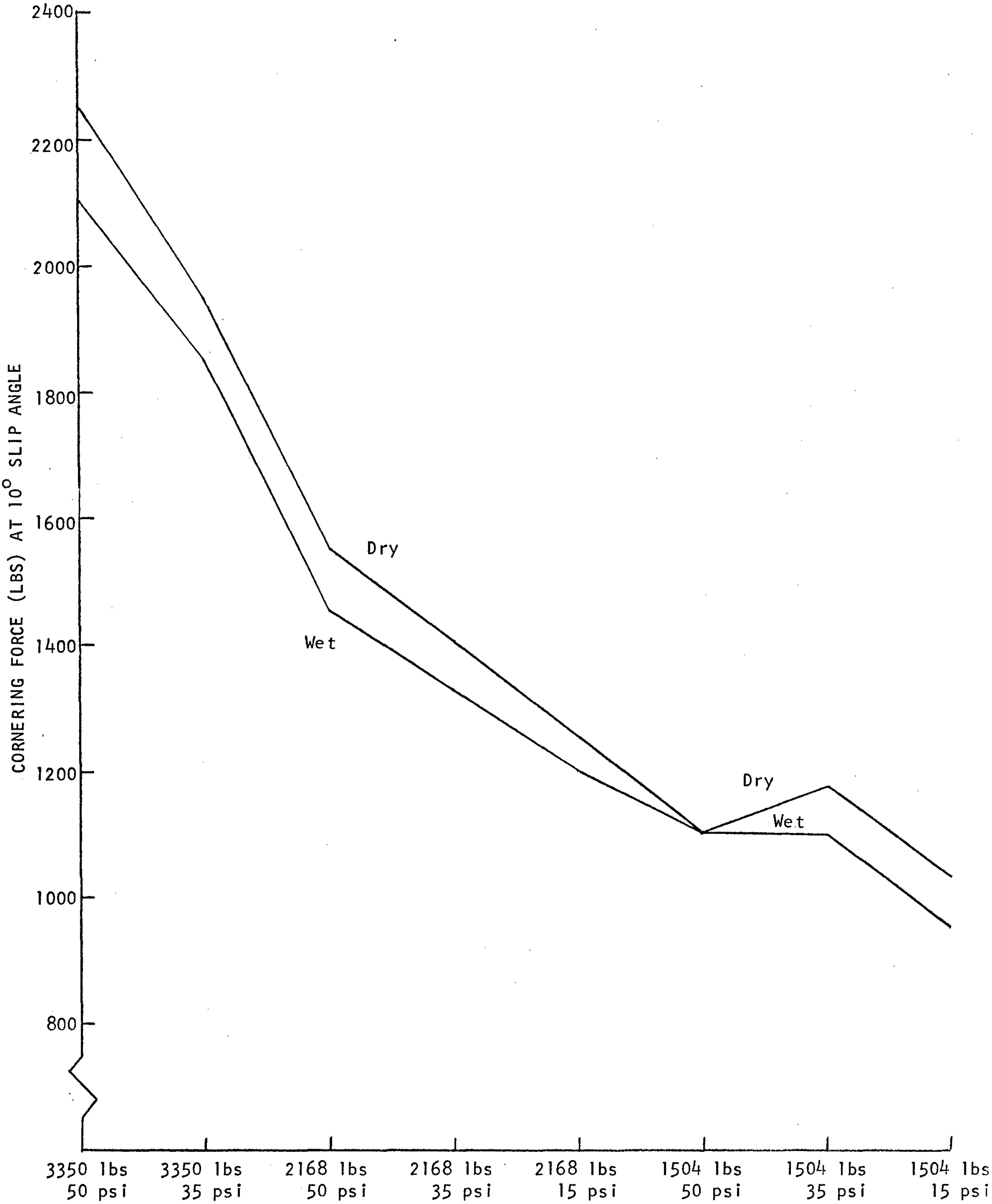


FIGURE 23. CORNERING FORCE PERFORMANCE OF TIRE E

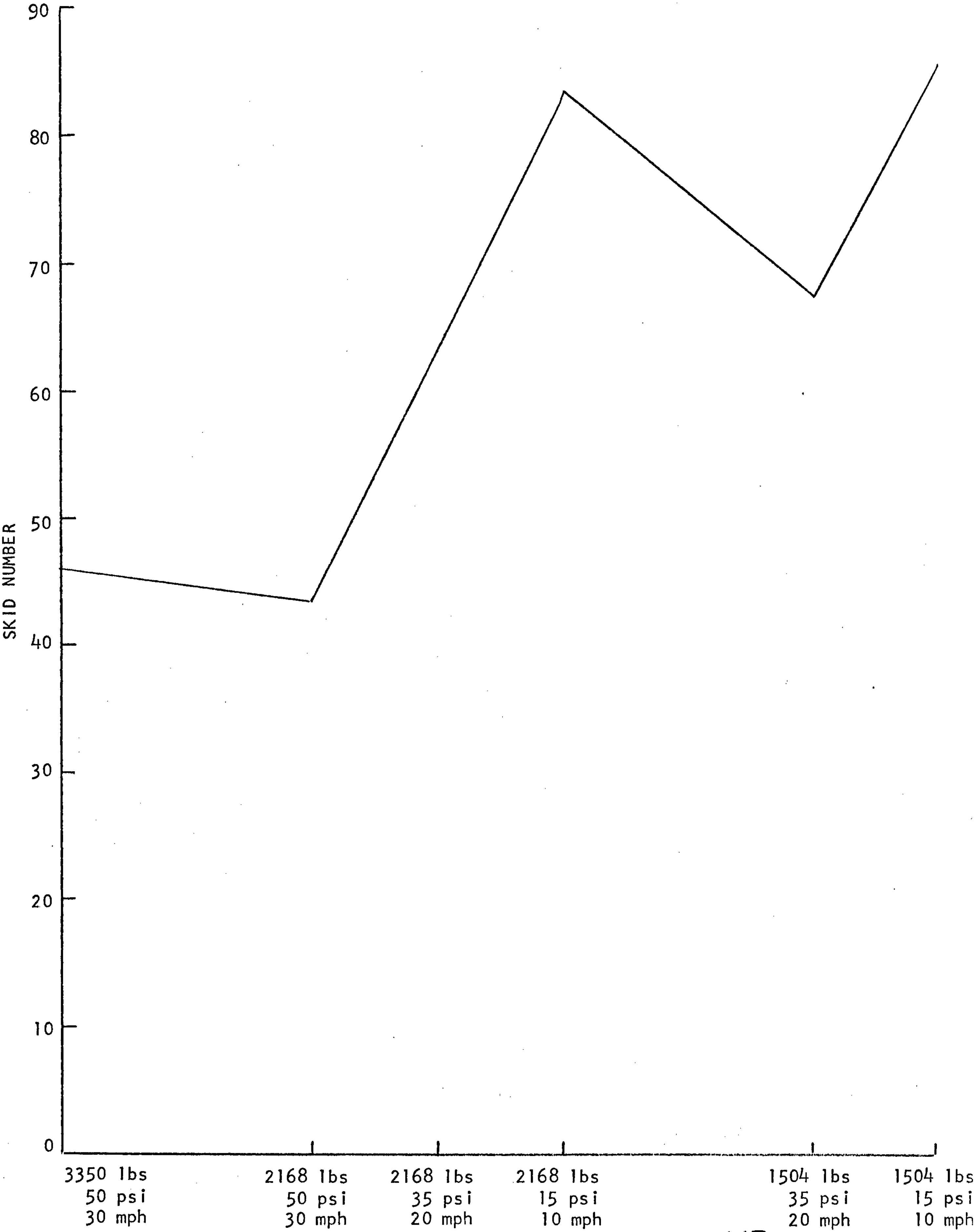


FIGURE 24. BRAKING PERFORMANCE OF TIRE ~~X~~ J

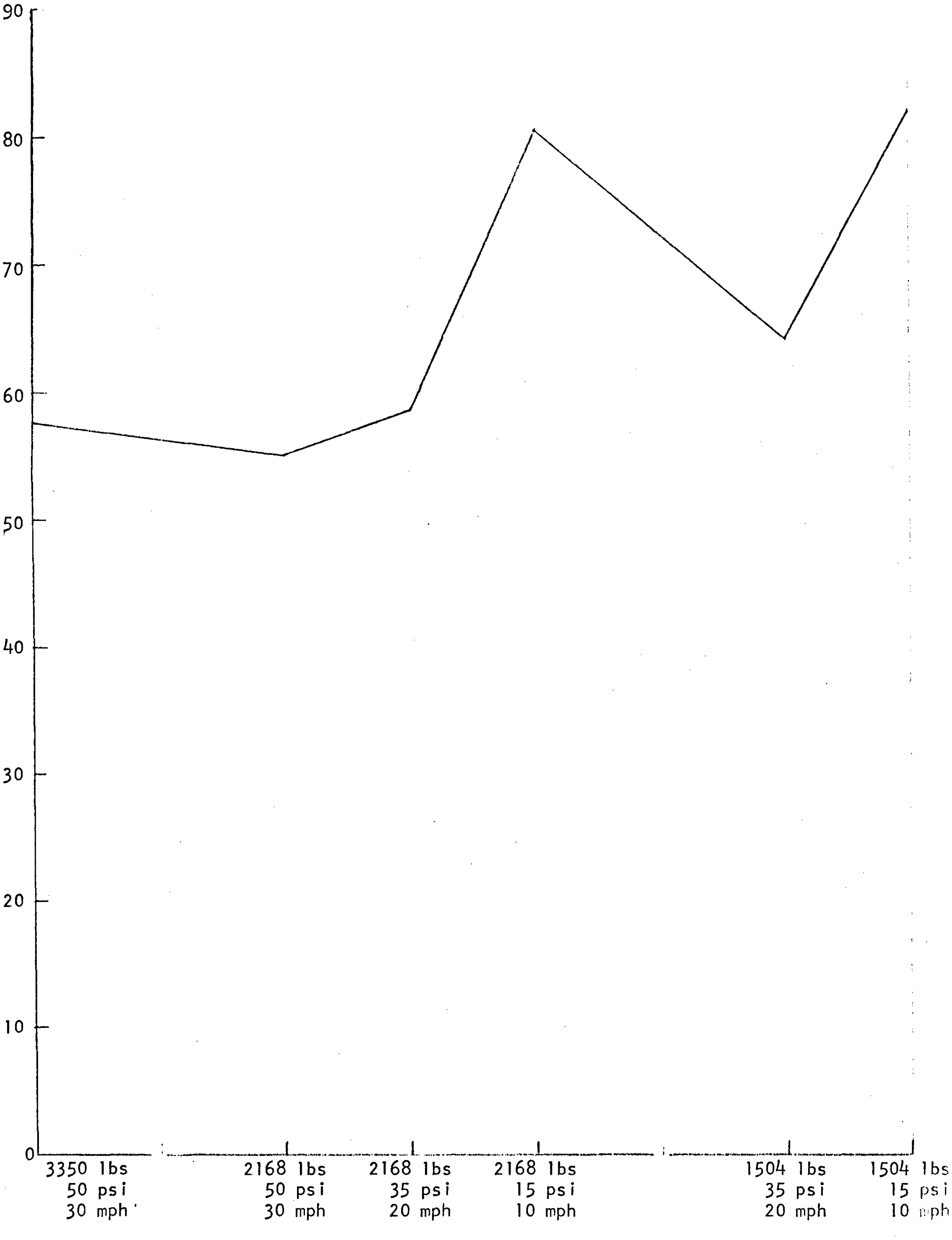


FIGURE 25. BRAKING PERFORMANCE OF TIRE G

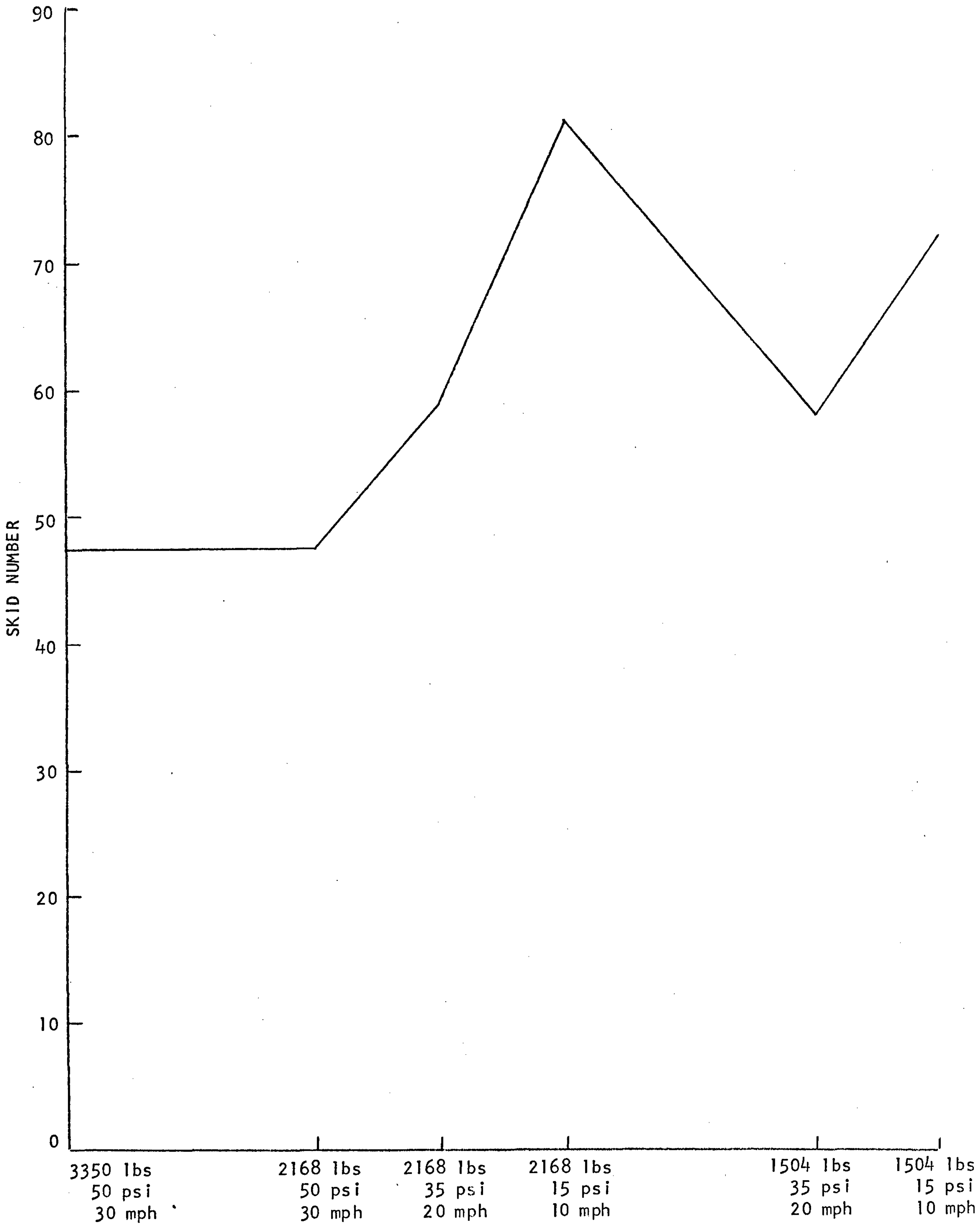


FIGURE 26. BRAKING PERFORMANCE OF TIRE C

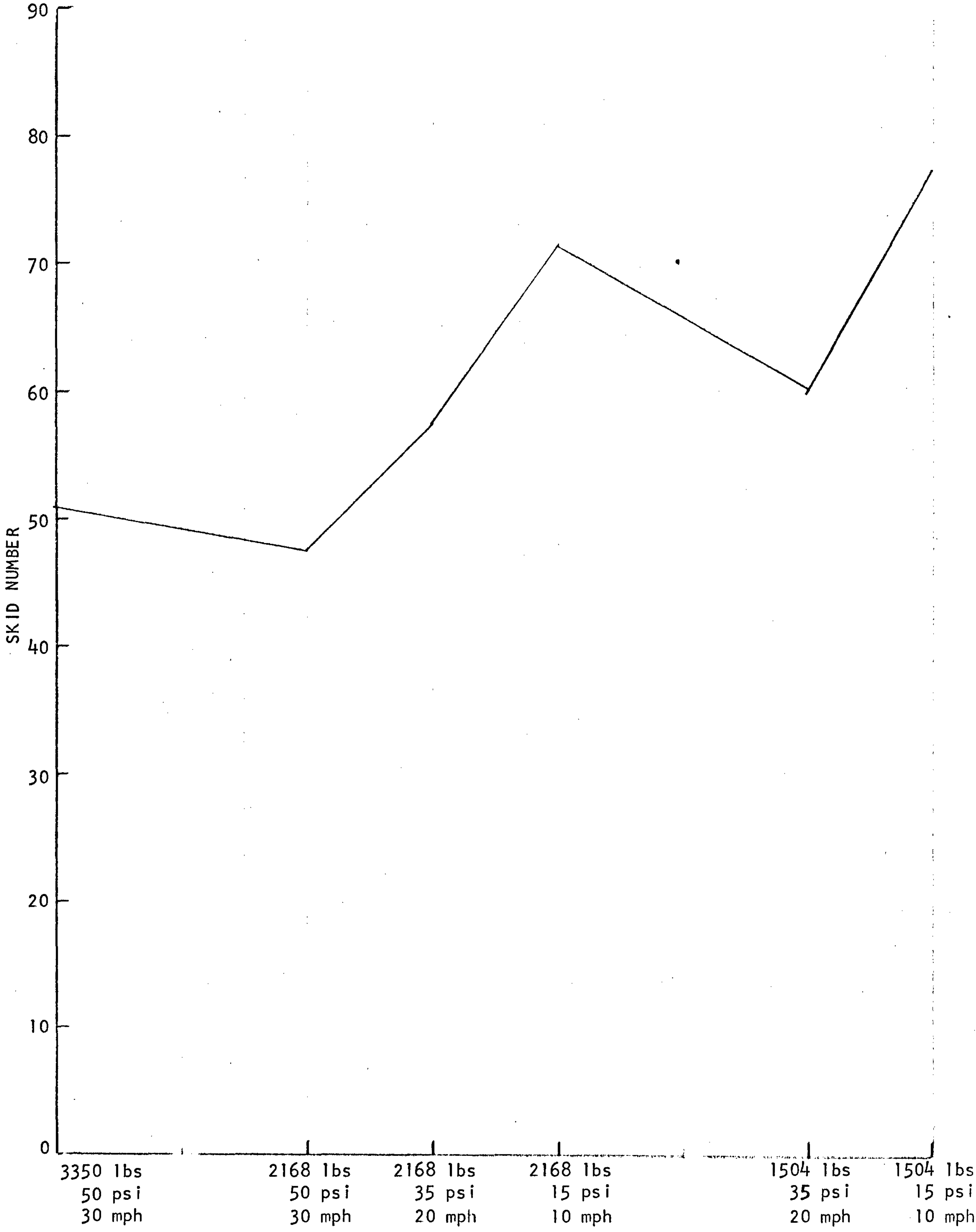


FIGURE 27. BRAKING PERFORMANCE OF TIRE I

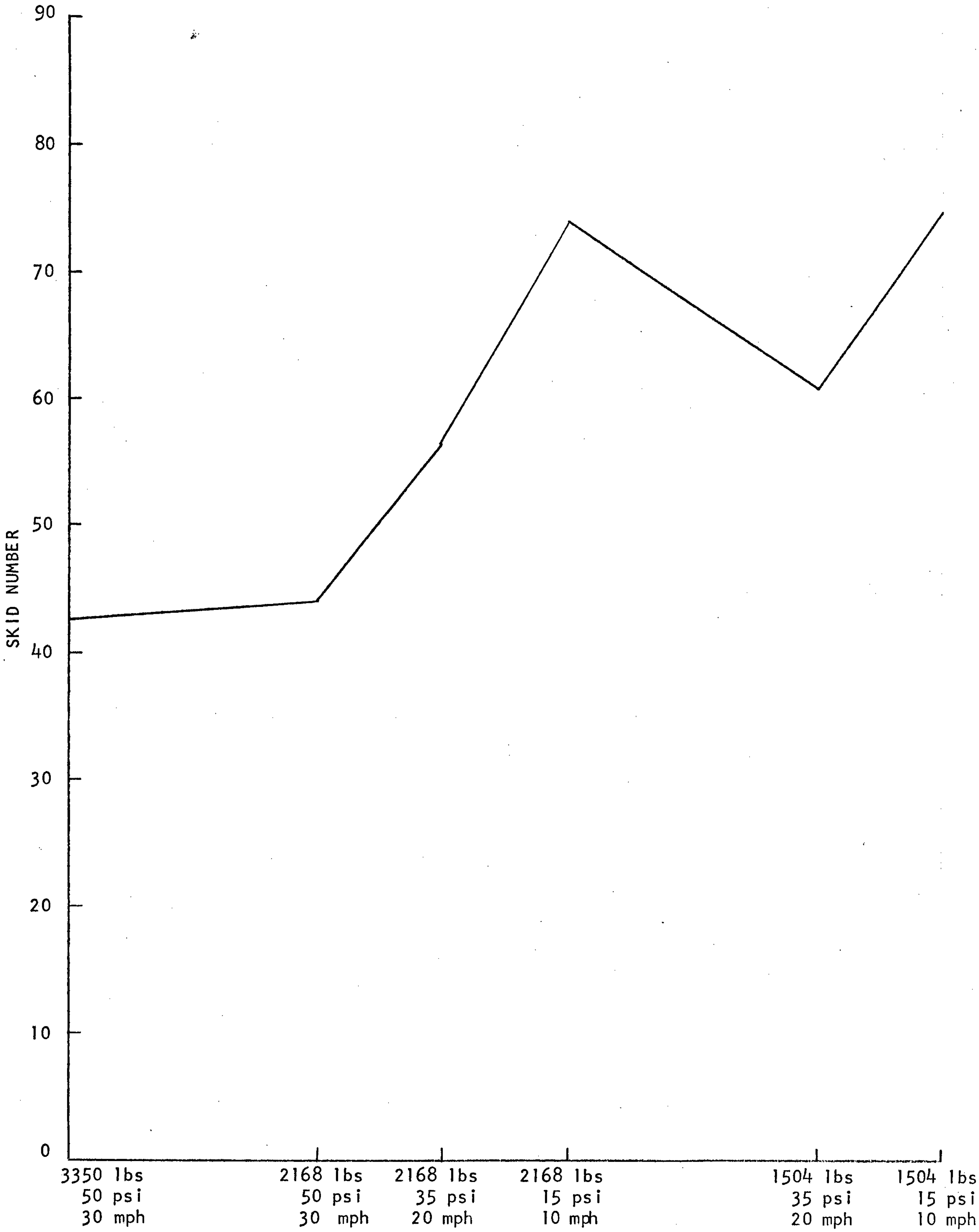


FIGURE 28. BRAKING PERFORMANCE OF TIRE D

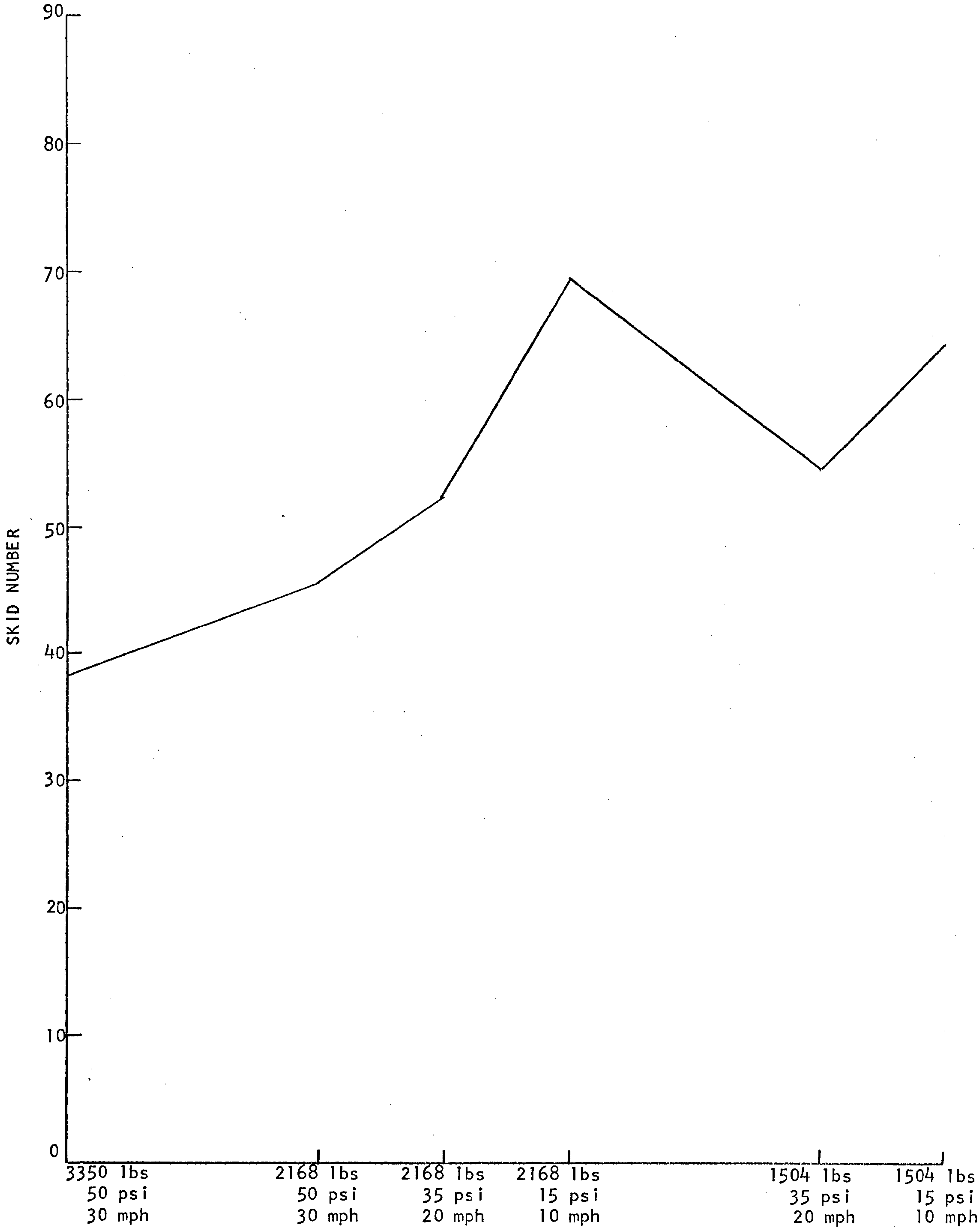


FIGURE 29. BRAKING PERFORMANCE OF TIRE A

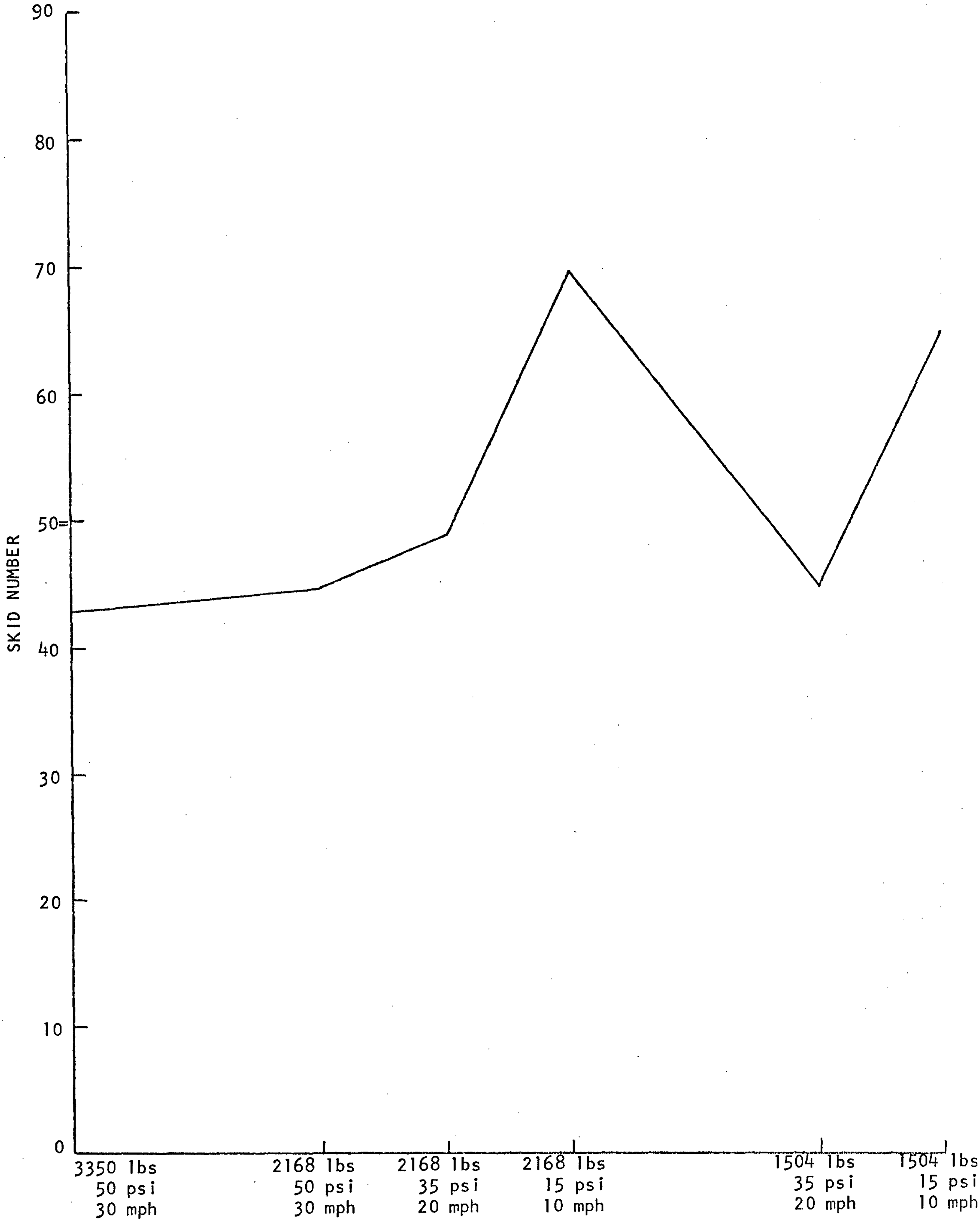


FIGURE 30. BRAKING PERFORMANCE OF TIRE E

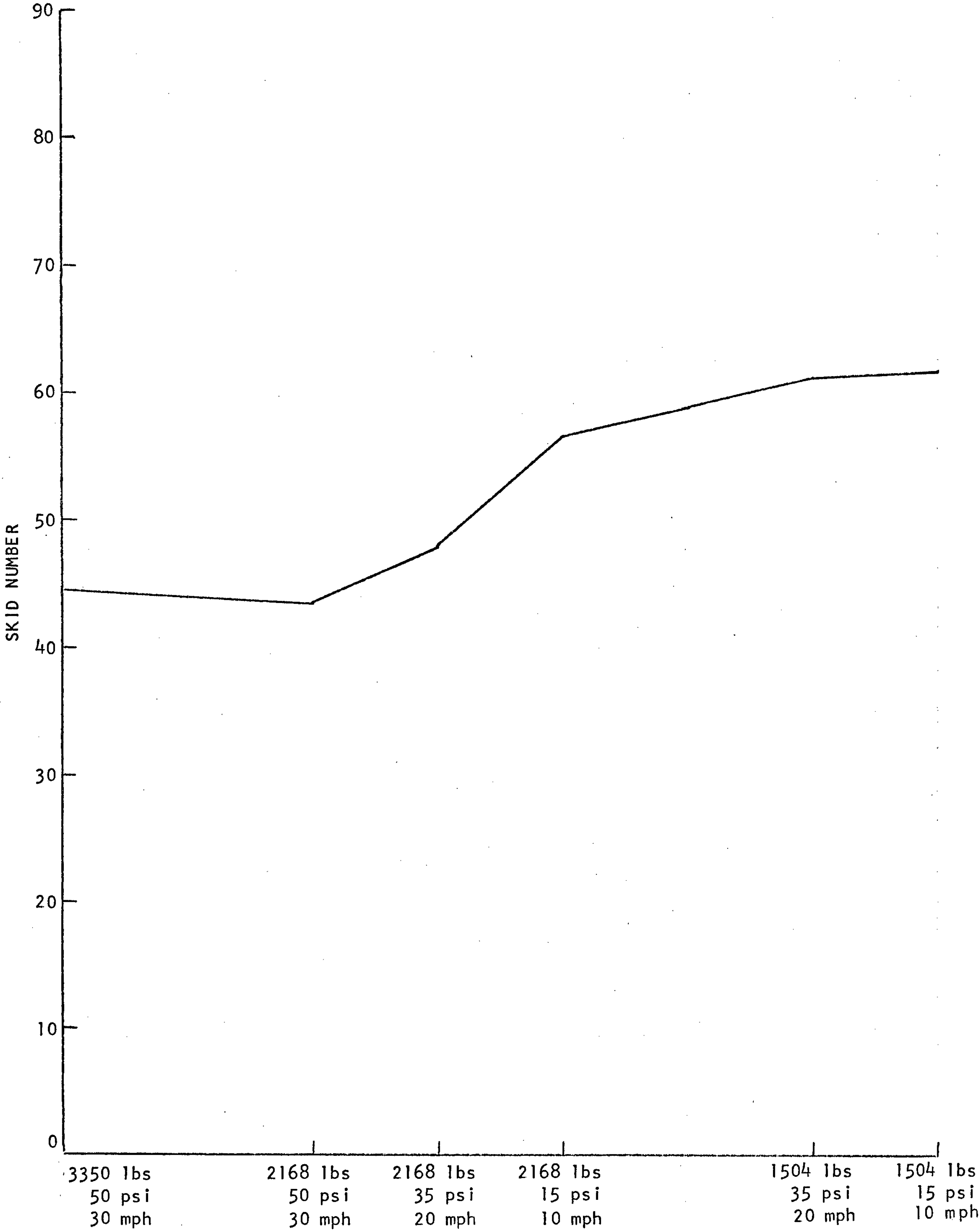


FIGURE 31. BRAKING PERFORMANCE OF TIRE B

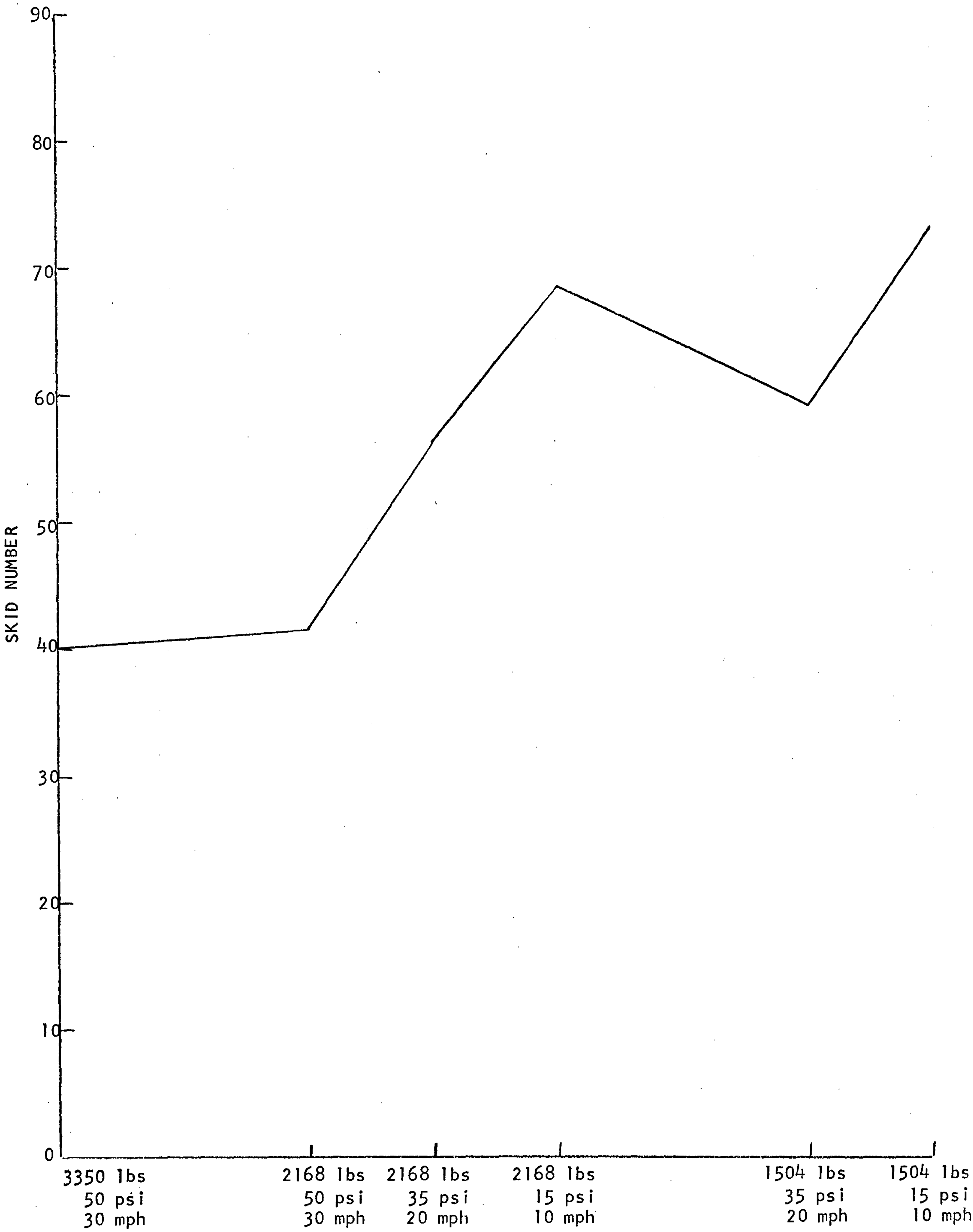


FIGURE 32. BRAKING PERFORMANCE OF TIRE F

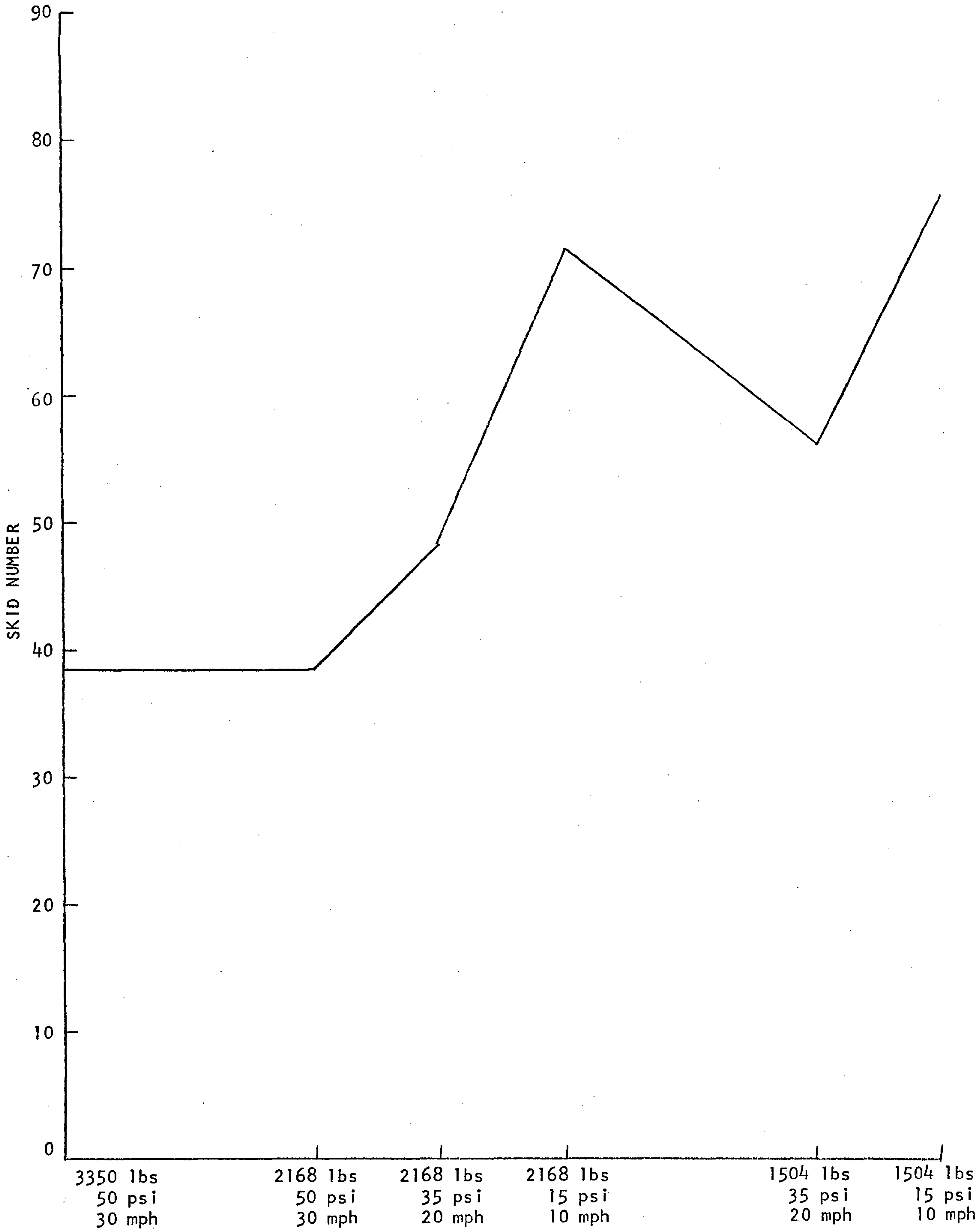


FIGURE 33. BRAKING PERFORMANCE OF TIRE H

CONCLUSIONS

From the data presented, there are no large differences in overall performance between the various tires. There is, however, a gradation between the best and worst tires. Of significance, the effects of rubber compounding, known to be important* are not controlled in this study. With these restrictions we can conclude:

1. The adoption of tread patterns G(or J), C or D will improve on-road braking and cornering performance over the current NDCC pattern (tire 1).

2. The differences in performance between the other tires are not significant.

RECOMMENDATIONS

1. Similar tests be conducted in size 7.00-16 (1/4-ton truck size) to determine if similar trends exist at that size and where higher speed tests will not be as dangerous. These higher speeds should show greater differences between wet and dry performance.

2. Analyses be made of performance versus various tread pattern parameters to determine if there is sufficient correlation that can be used in future tread design.

3. If future tests are to be conducted, rubber compound and carcass construction should be identical.

4. Combined braking and turning, which occurs in emergency situations, is worthy of investigation.

---

*Kelley, J. D. and Albert, B. J., "Tread Design of Tire Affects Wet Traction Most," SAE Journal, September 1968.

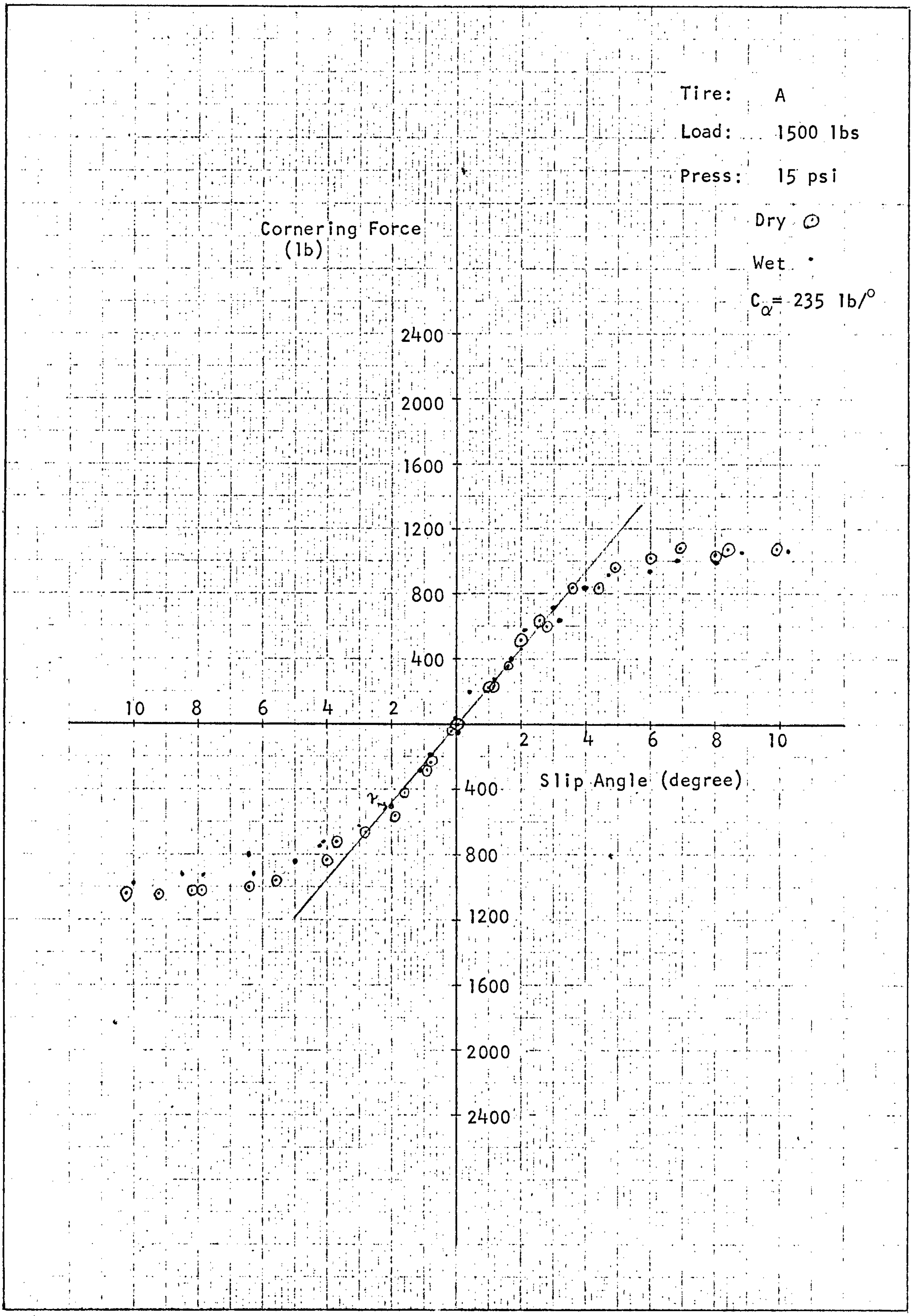
ACKNOWLEDGEMENTS

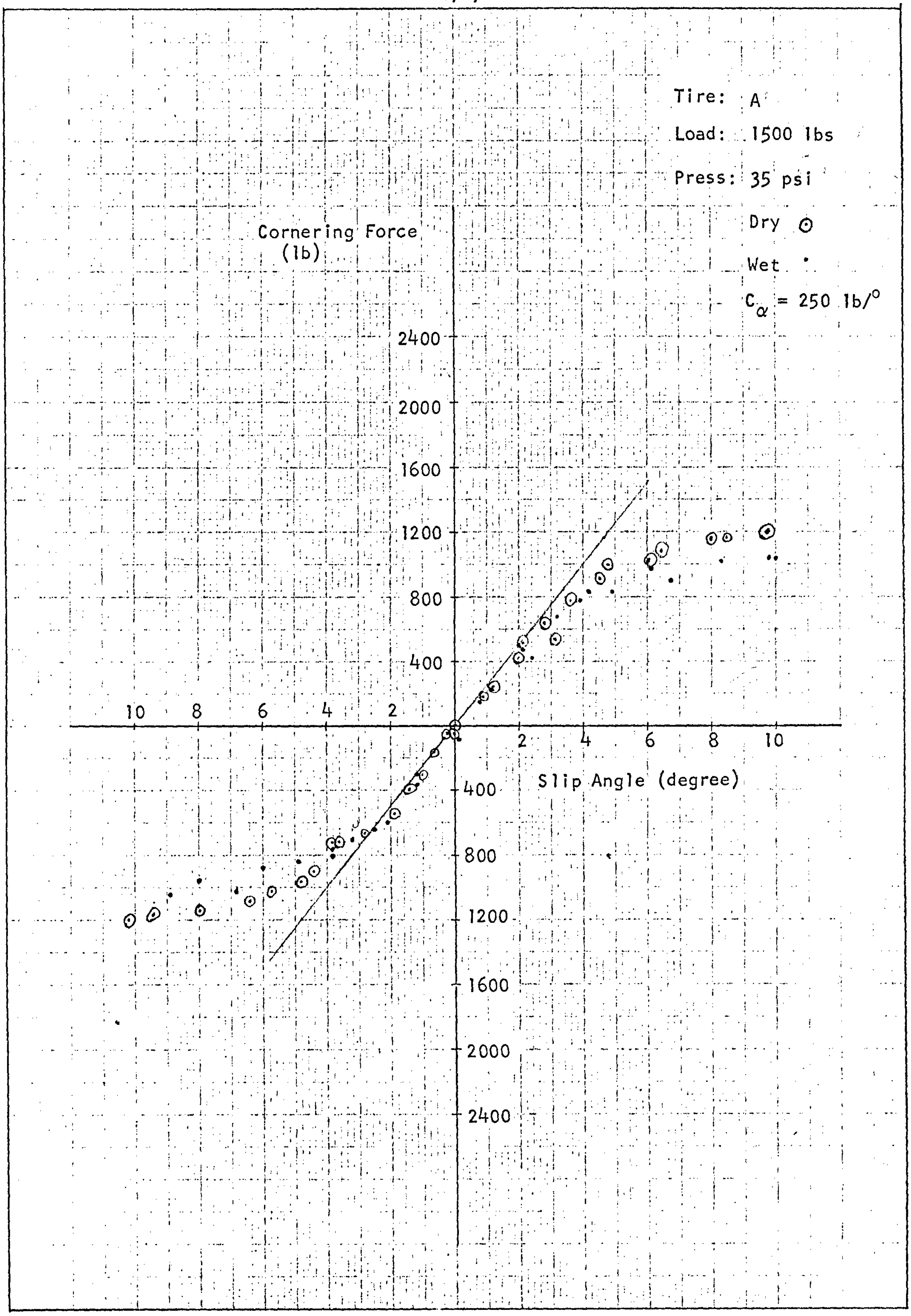
The authors wish to acknowledge the contributions of Mr. Roger Kirk of the U. S. Army Tank-Automotive Command who was the contract technical monitor of this program and provided many valuable suggestions. Also, recognition must be accorded to Mr. I. O. Kamm who supervised the construction of the test trailer and to Mr. Awni Boutros who did the tedious work of taking the raw data from the strip charts and plotted them for our analysis.

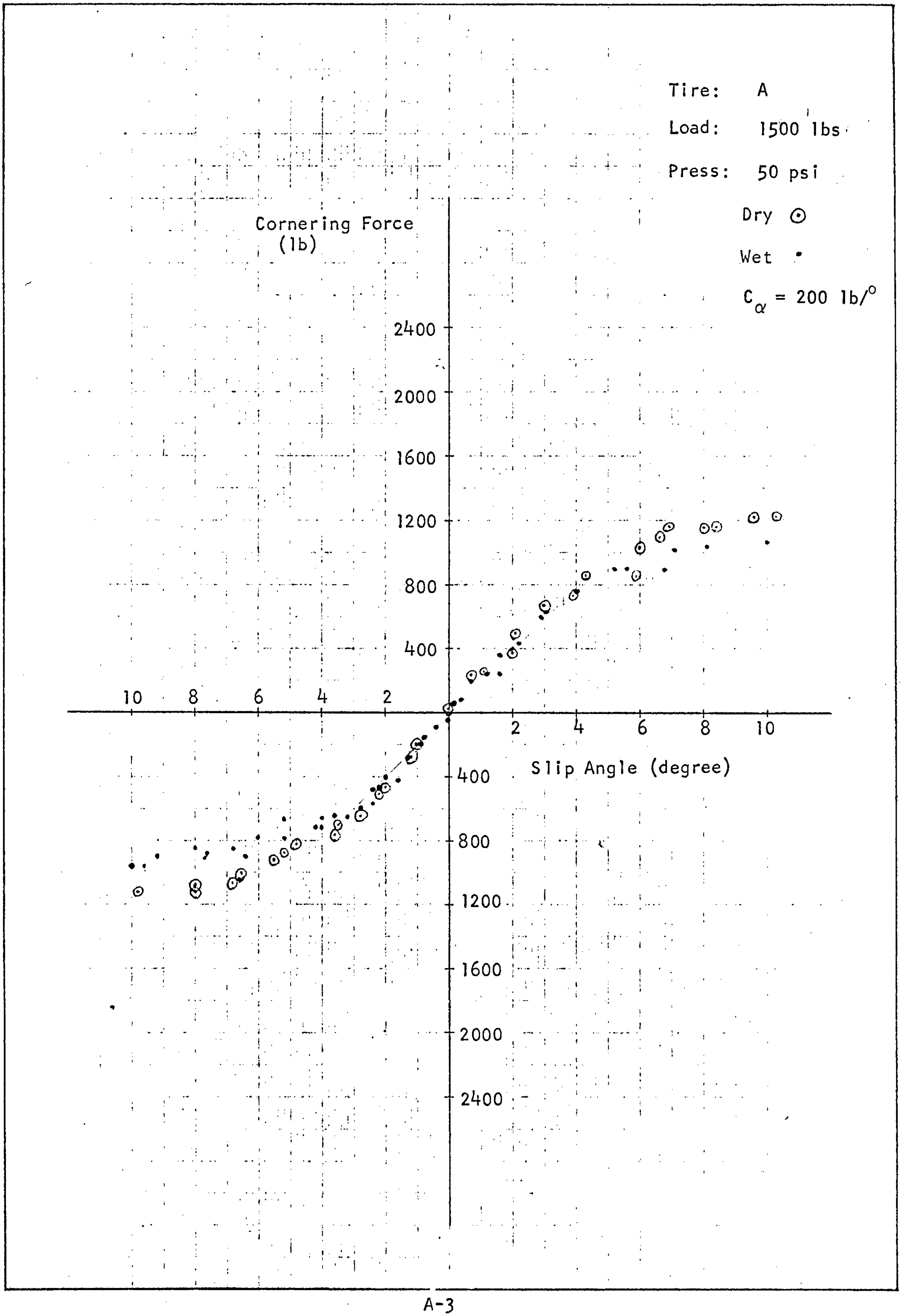
Special recognition must be made to the late Mr. C. W. Wilson. Long an active participant in many automotive test programs, the tests conducted here were Bill's final contribution.

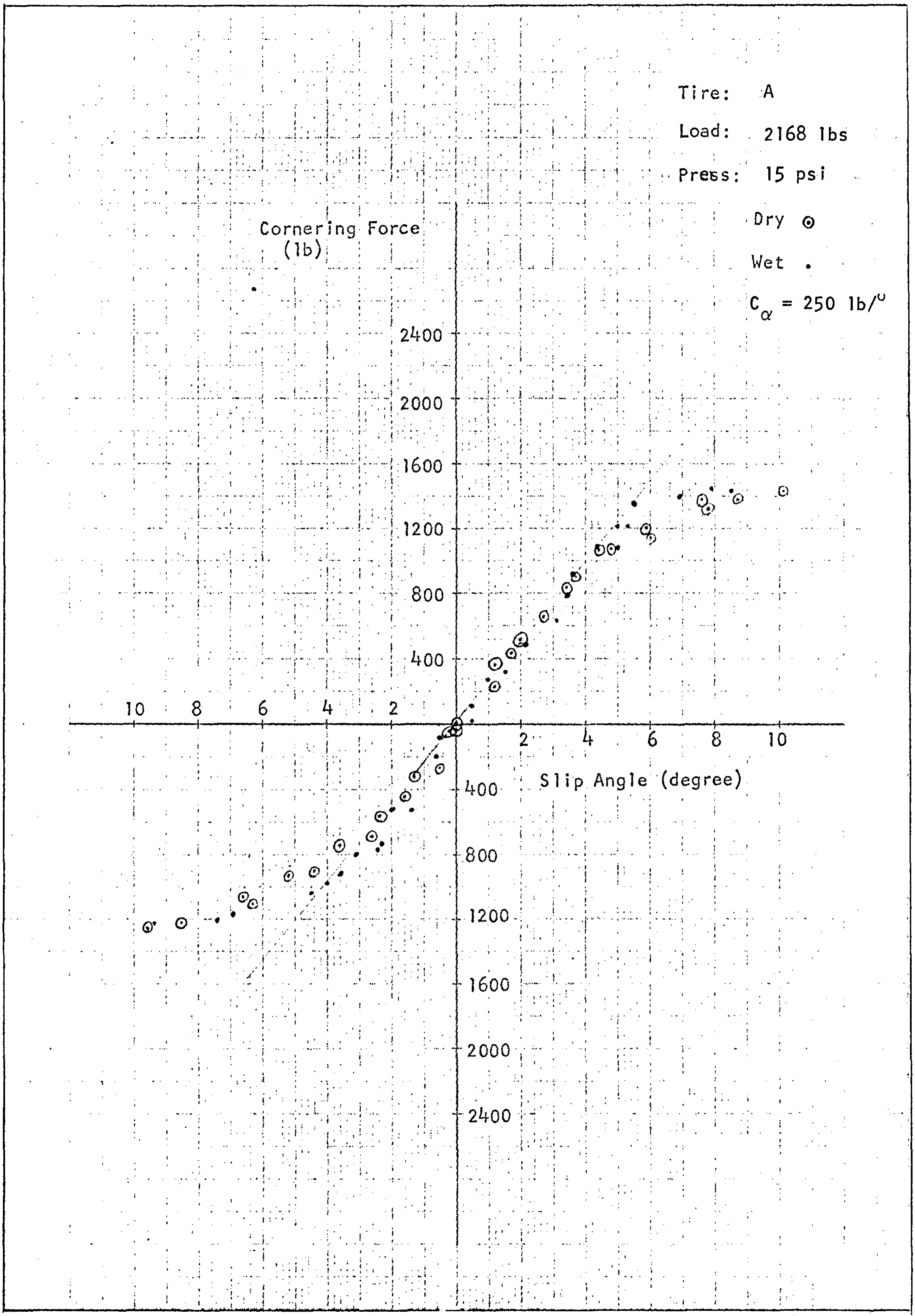
APPENDIX

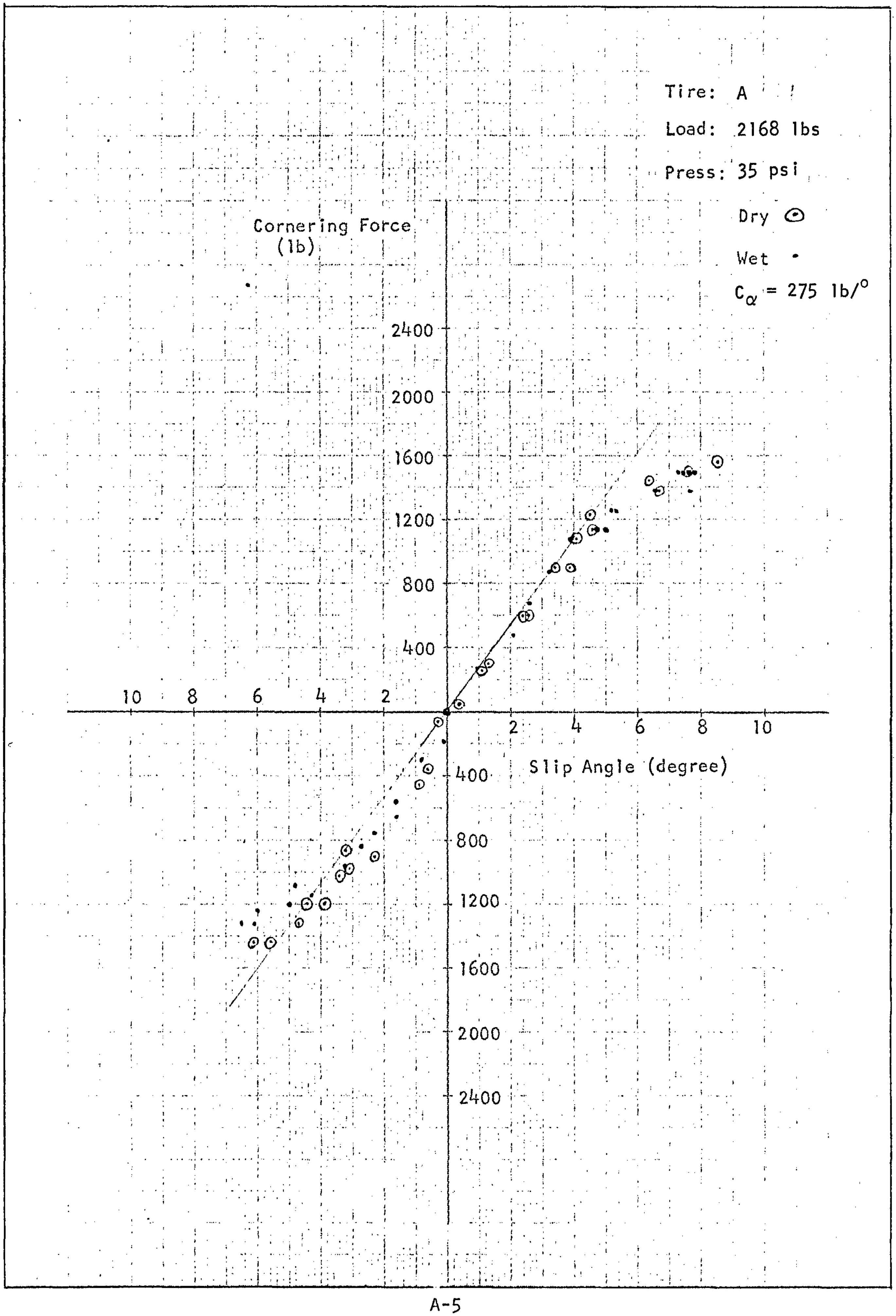
Cornering Force vs. Slip Angle for the Loads and Inflation Pressures Tested

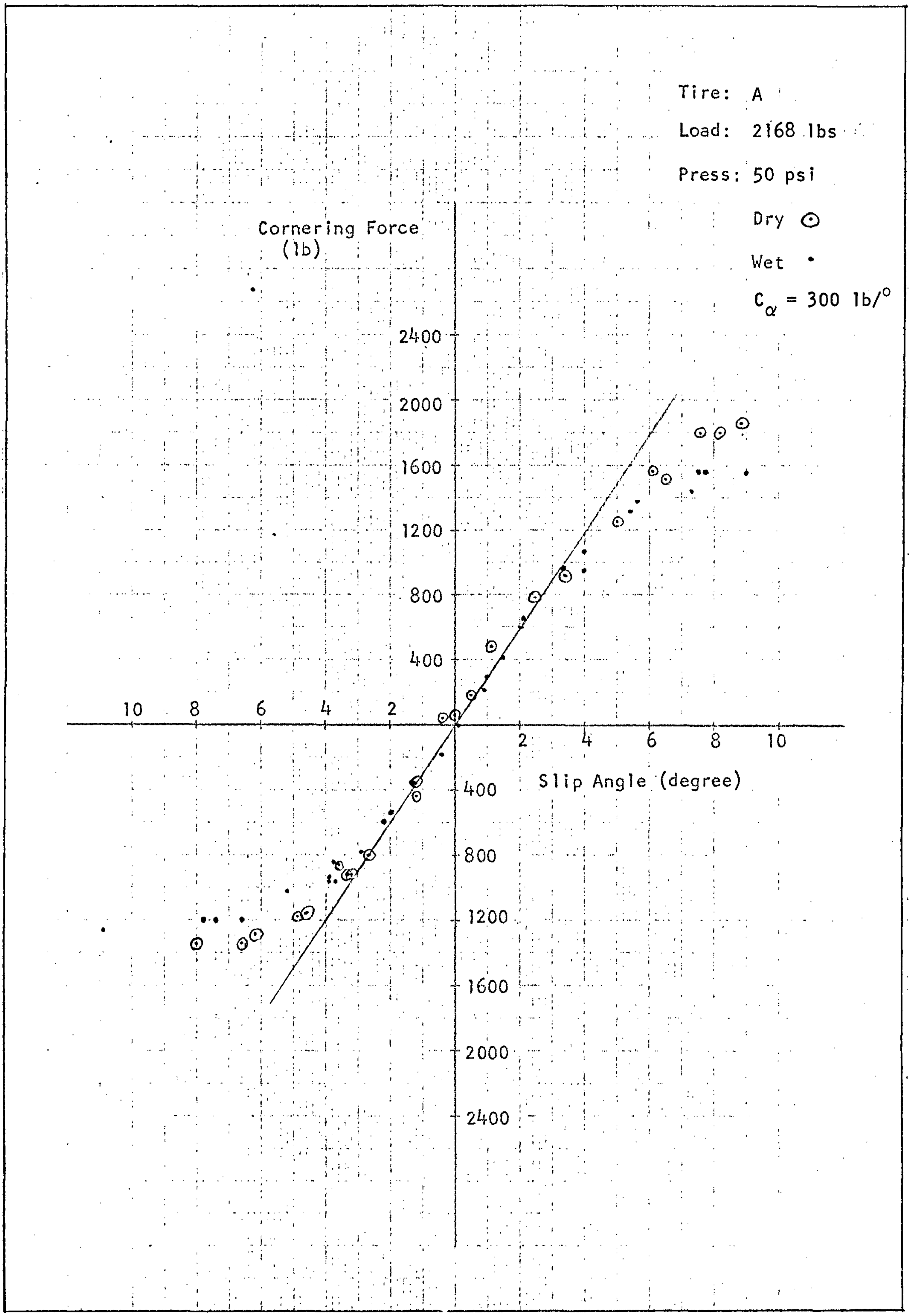

Tire: A
Load: 1500 lbs
Press: 15 psi
Dry
Wet
C_α = 235 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

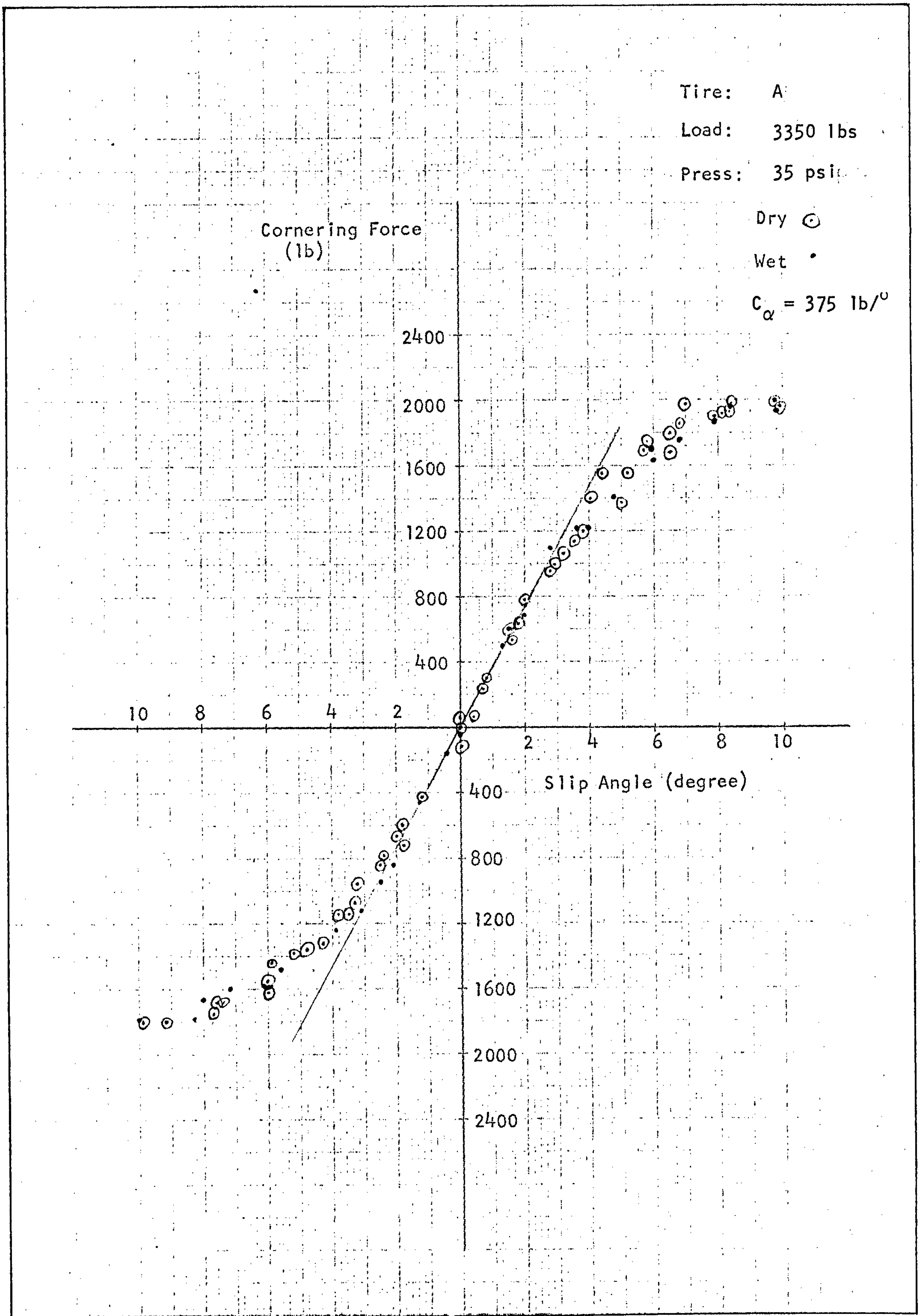

Tire: A
Load: 1500 lbs
Press: 35 psi
Dry ⊙
Wet •
C_α = 250 lb/°
Cornering Force (lb)
Slip Angle (degree)
2400
2000
1600
1200
800
400
10
8
6
4
2

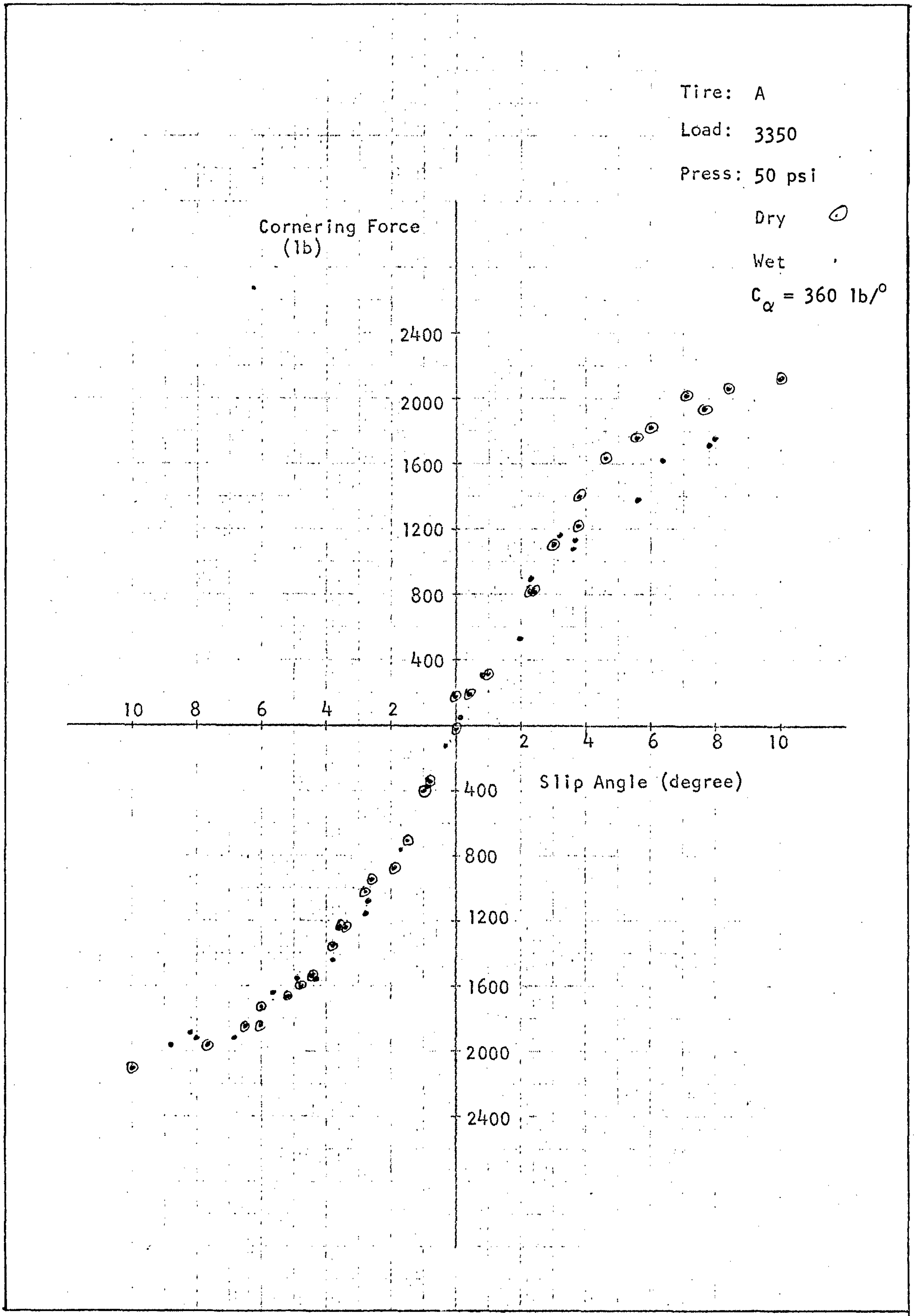

Tire: A
Load: 1500 lbs
Press: 50 psi
Dry ⊙
Wet •
C_α = 200 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

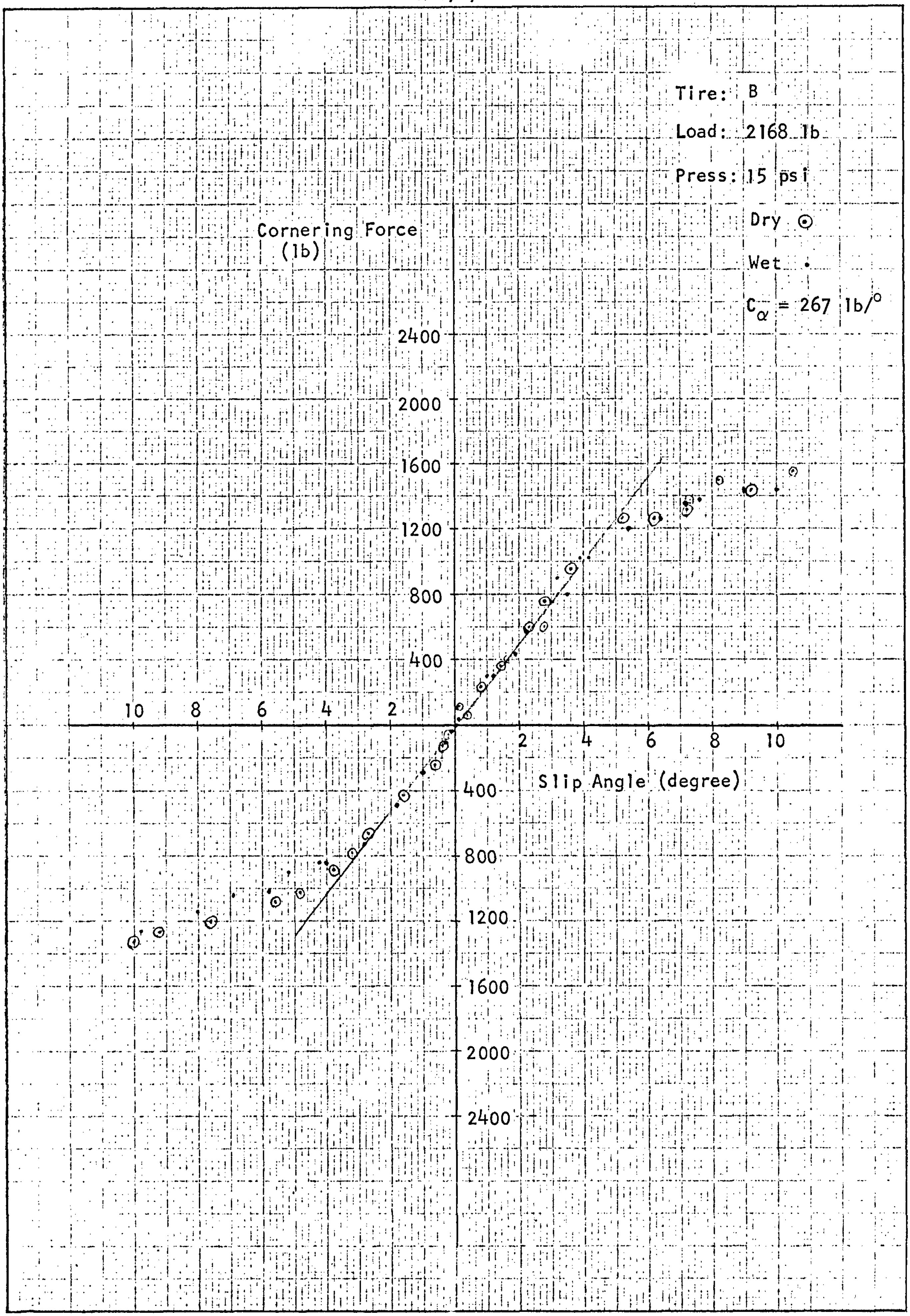

Tire: A
Load: 2168 lbs
Press: 15 psi
Dry ⊙
Wet •
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400

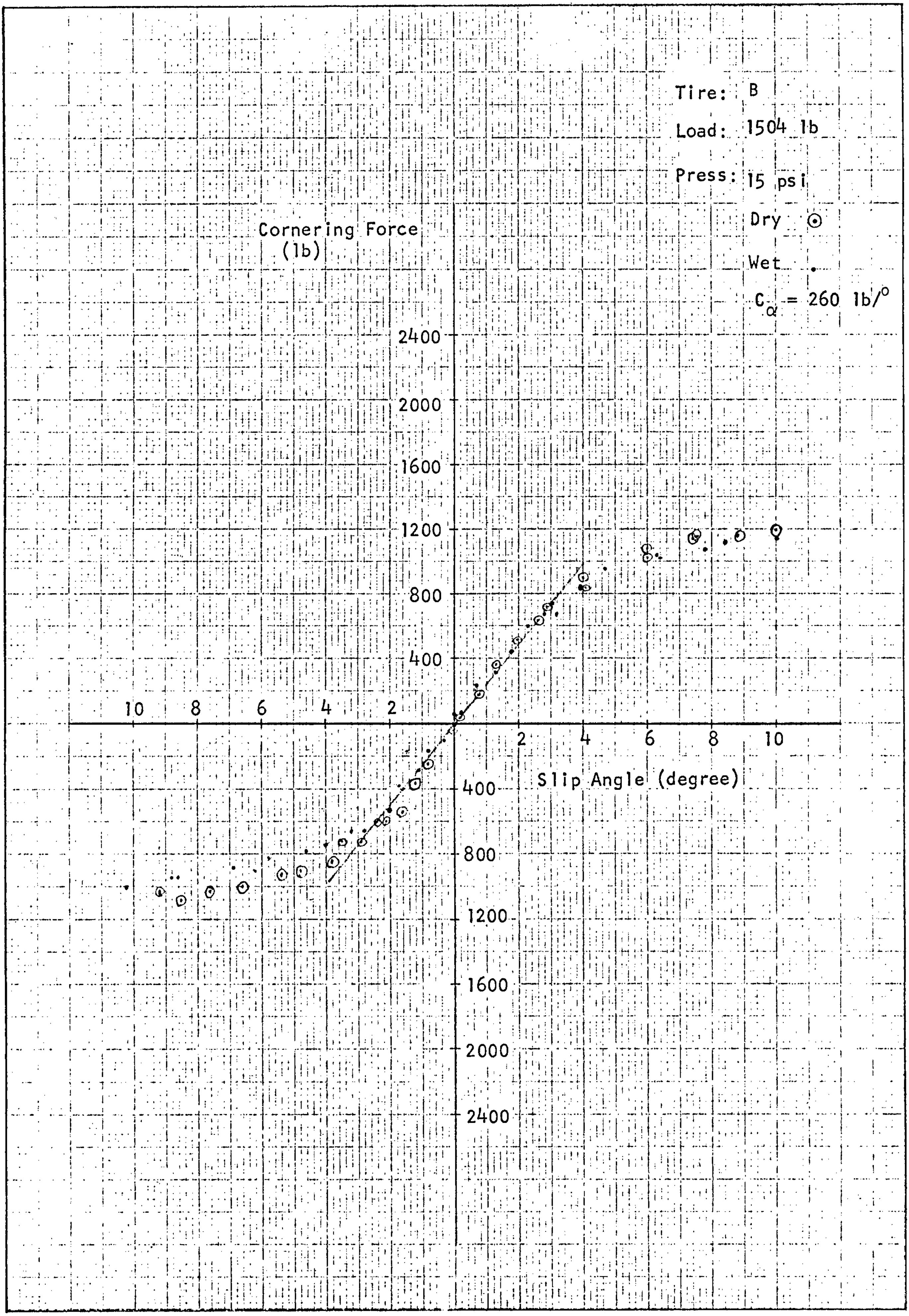

Tire: A
Load: 2168 lbs
Press: 35 psi
Dry
Wet
C_α = 275 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

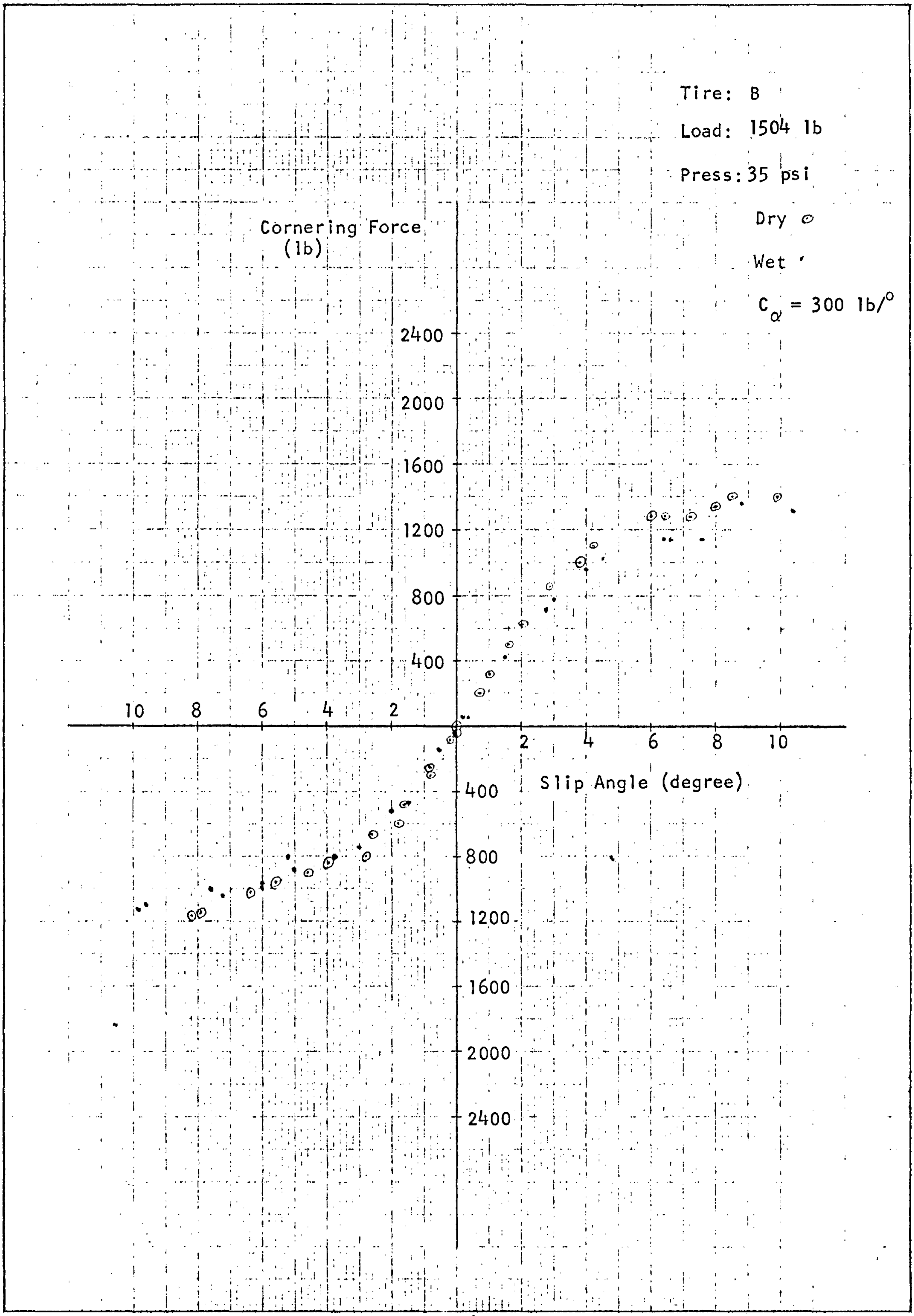

Tire: A
Load: 2168 lbs
Press: 50 psi
Dry
Wet
C_α = 300 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

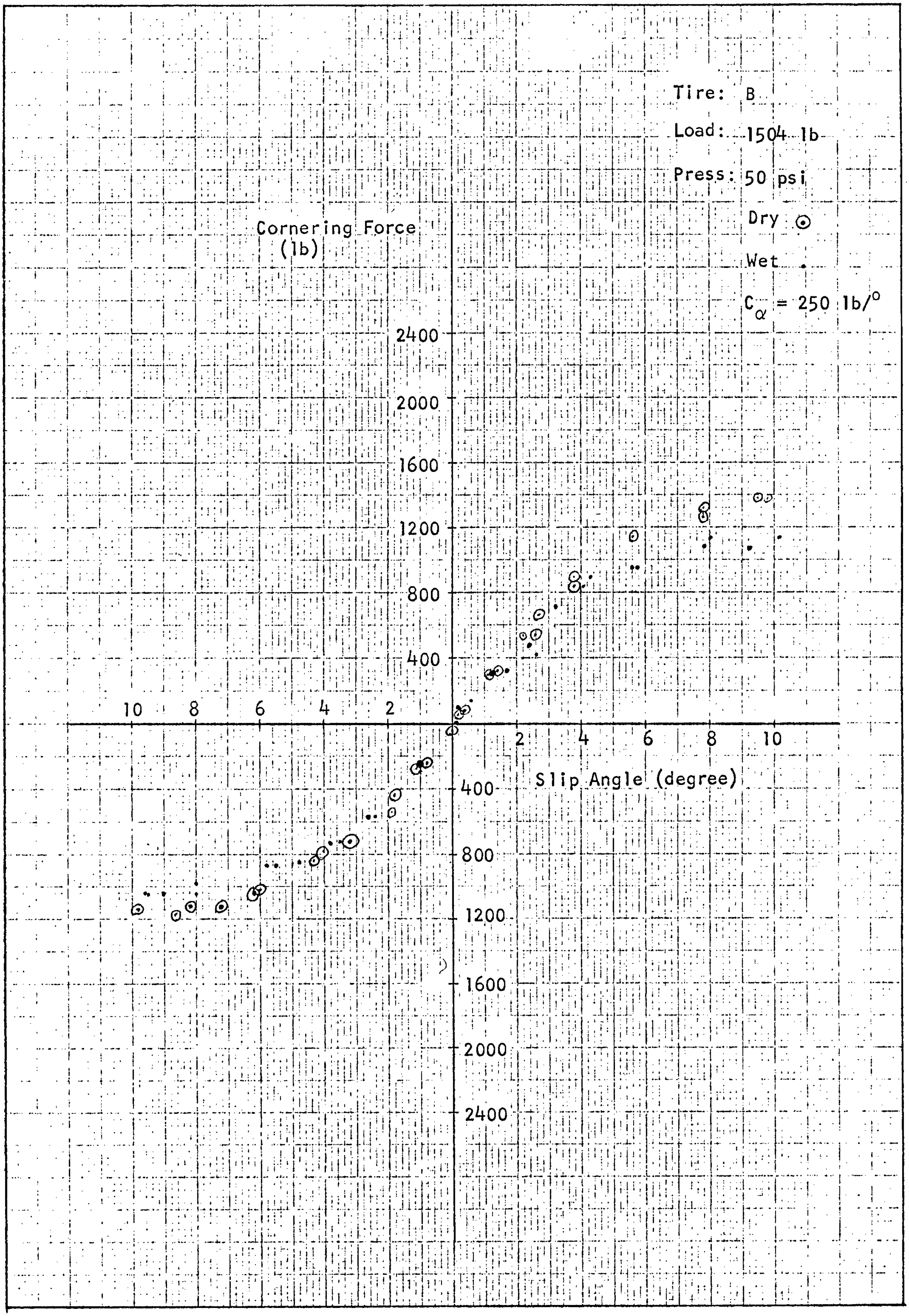

Tire: A
Load: 3350 lbs
Press: 35 psi
Dry
Wet
C_α = 375 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

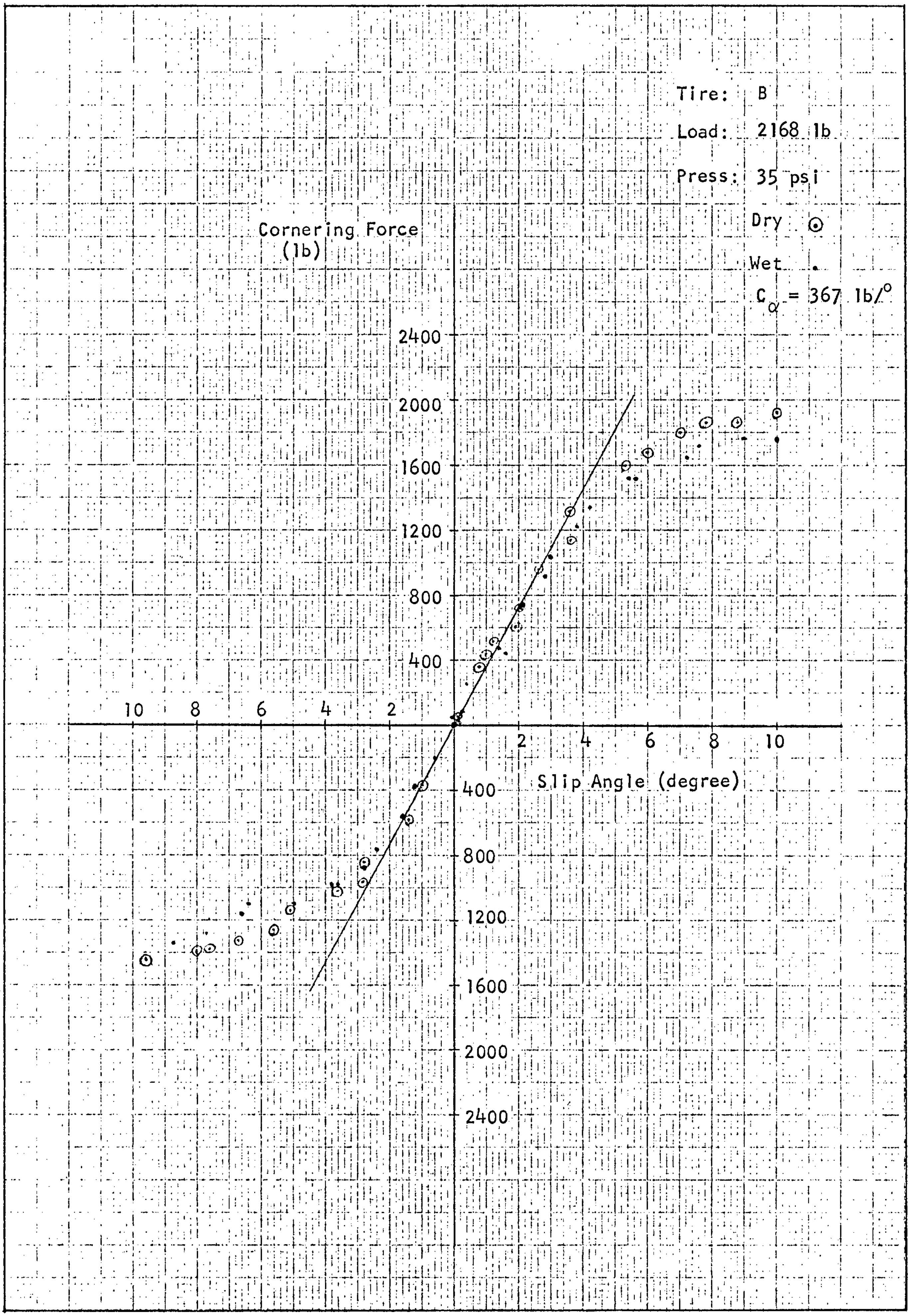

Tire: A
Load: 3350
Press: 50 psi
Dry
Wet
C_α = 360 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

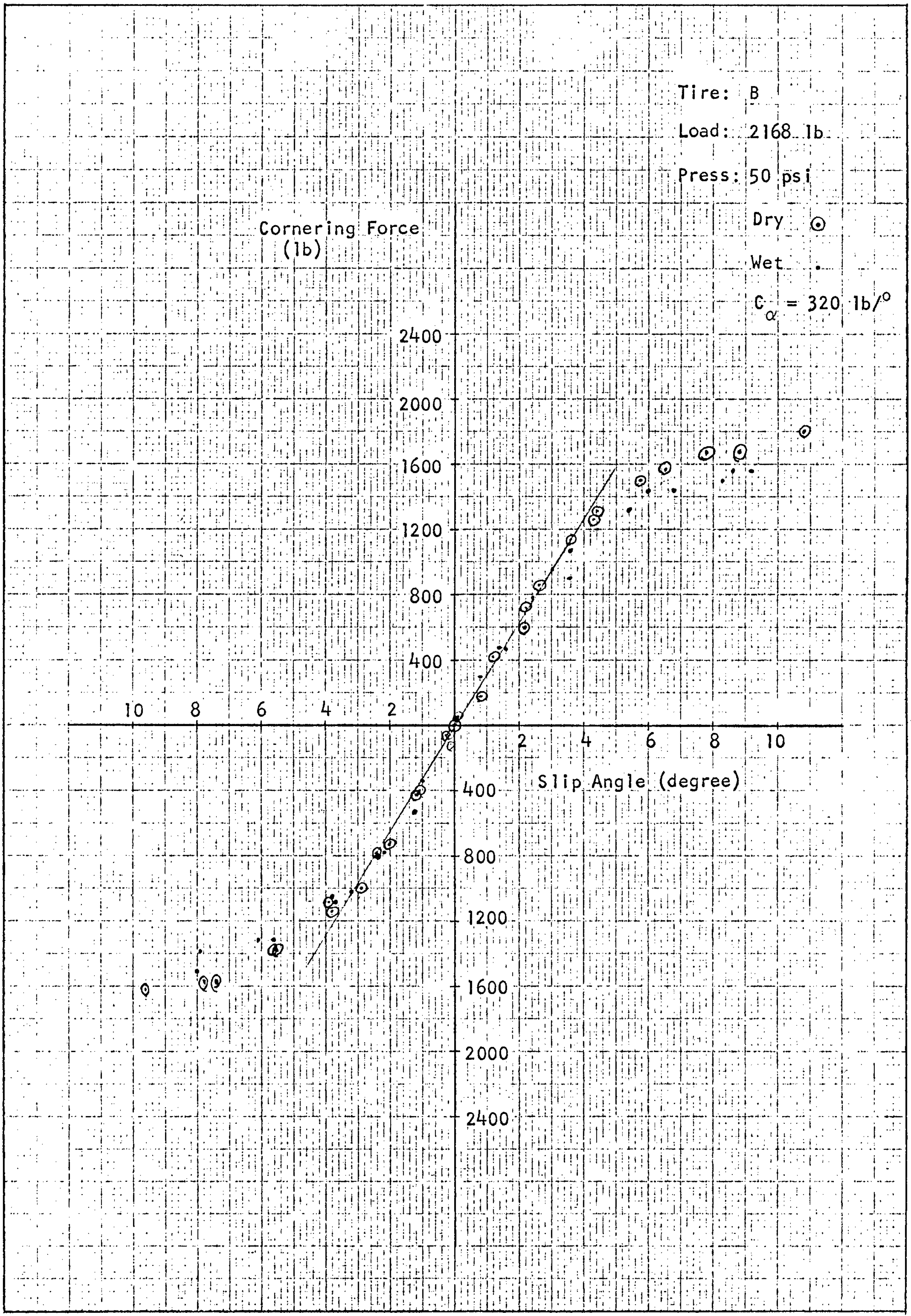

Tire: B
Load: 2168 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 267 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

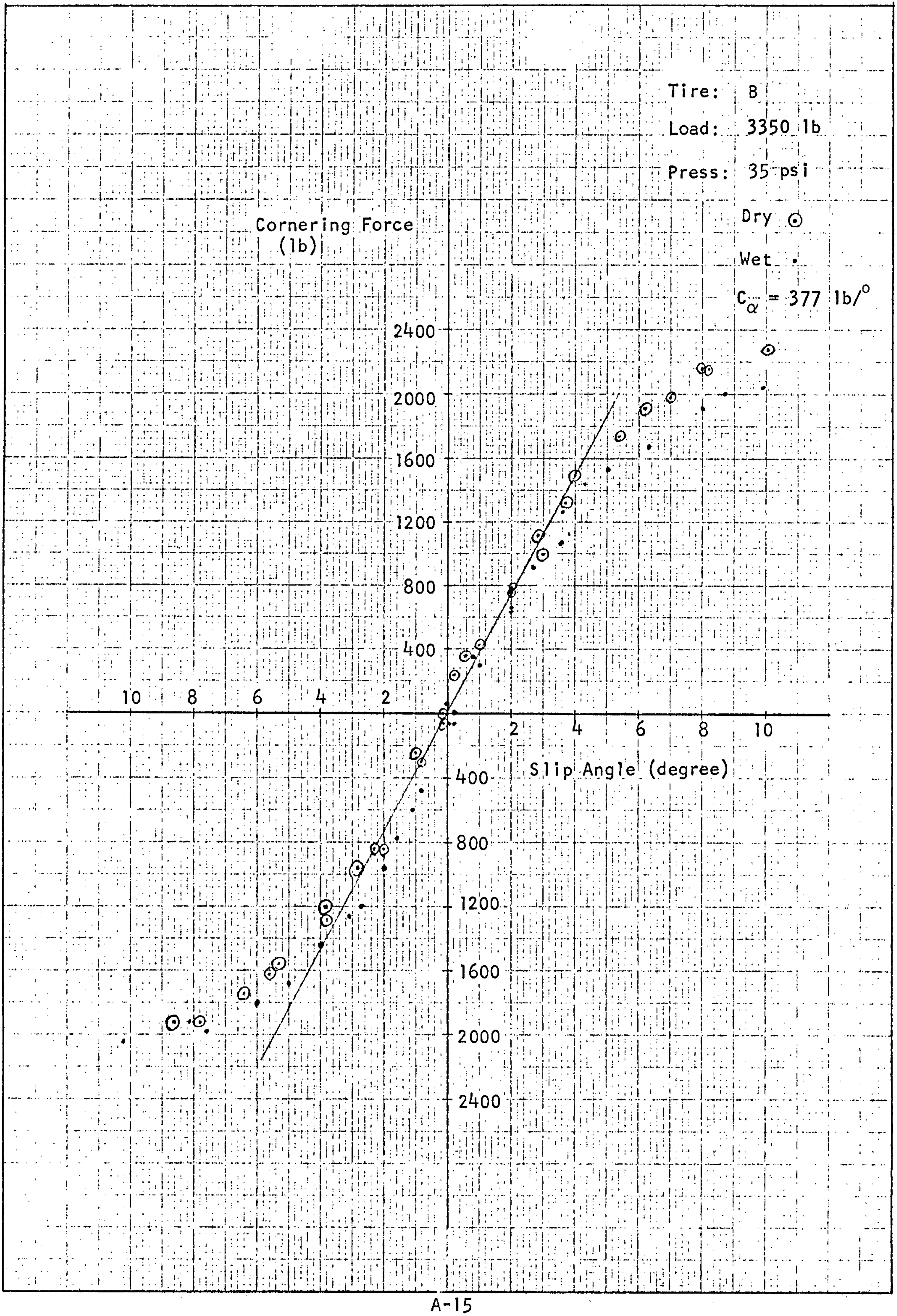

Tire: B
Load: 1504 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 260 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

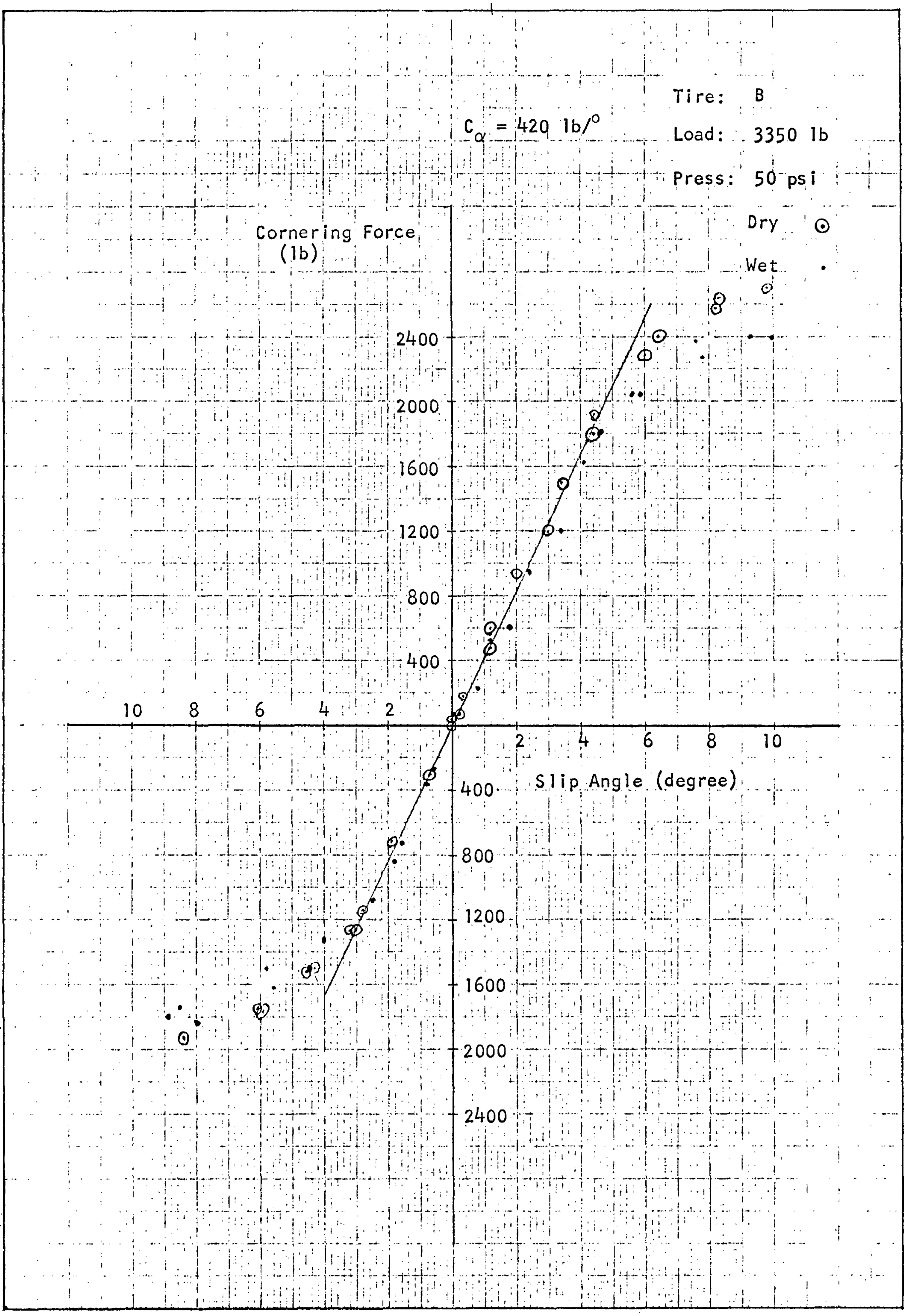

Tire: B
Load: 1504 lb
Press: 35 psi
Dry
Wet
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: B
Load: 1504 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

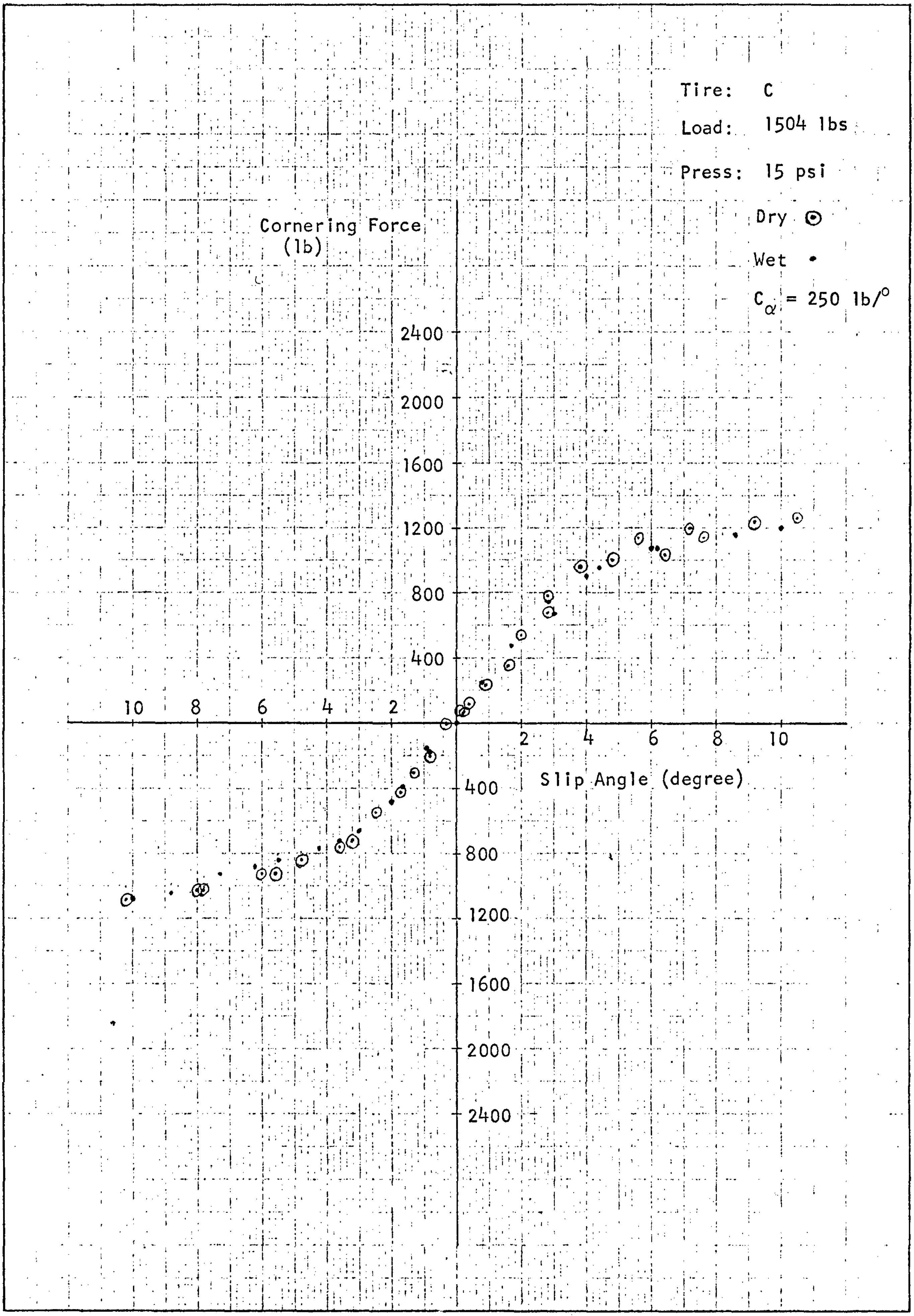

Tire: B
Load: 2168 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 367 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400

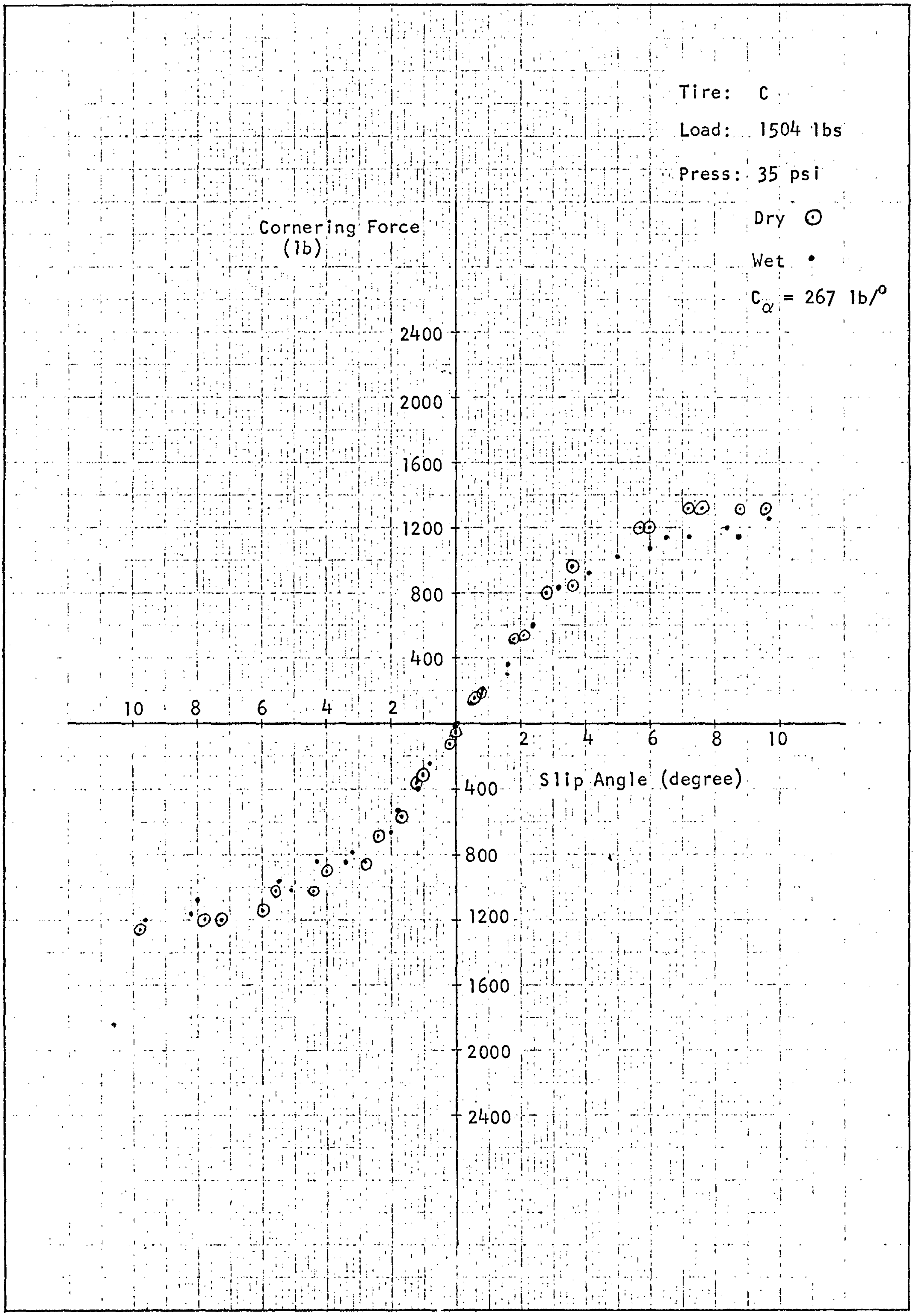

Tire: B
Load: 2168 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 320 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

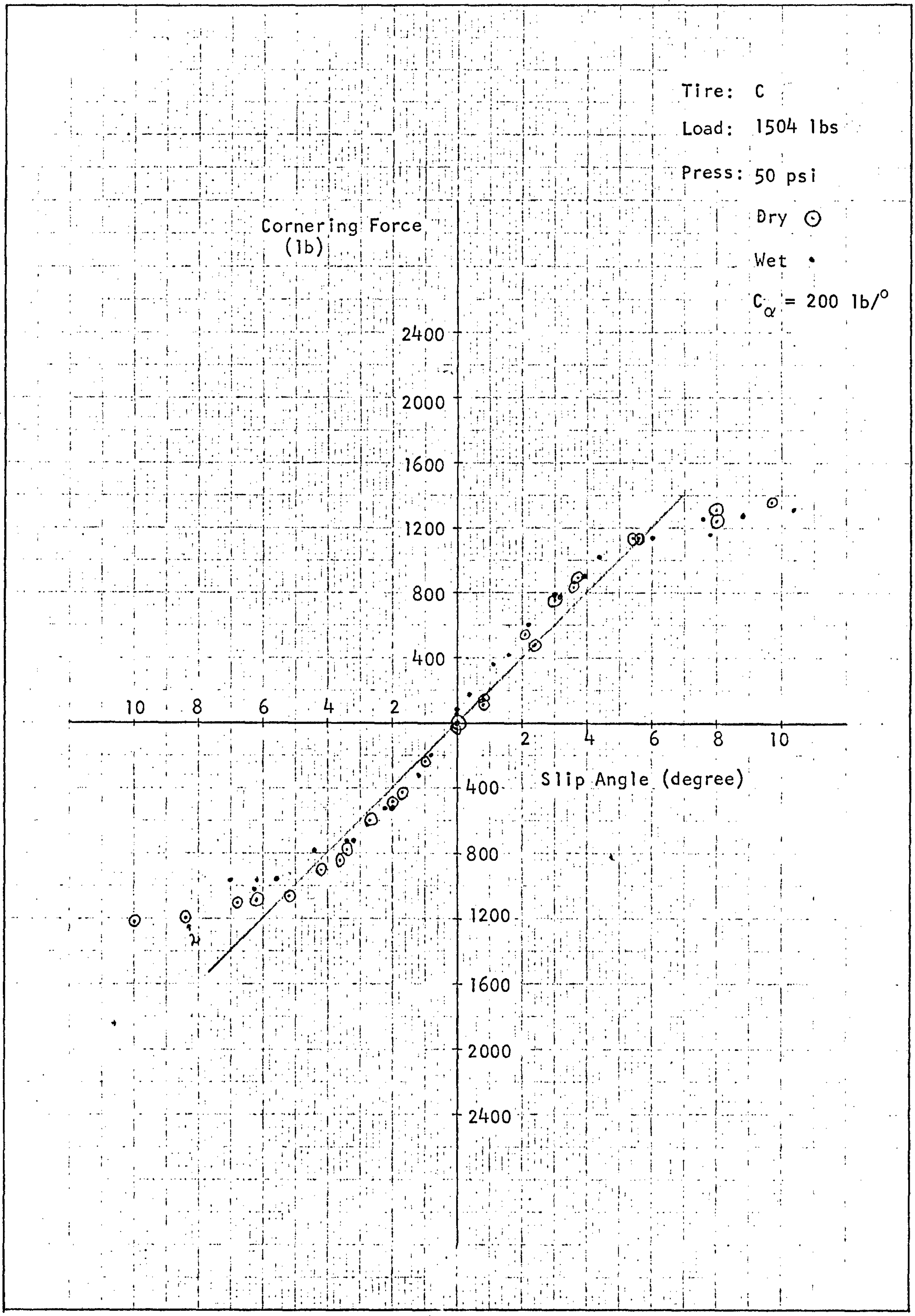

Tire: B
Load: 3350 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 377 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

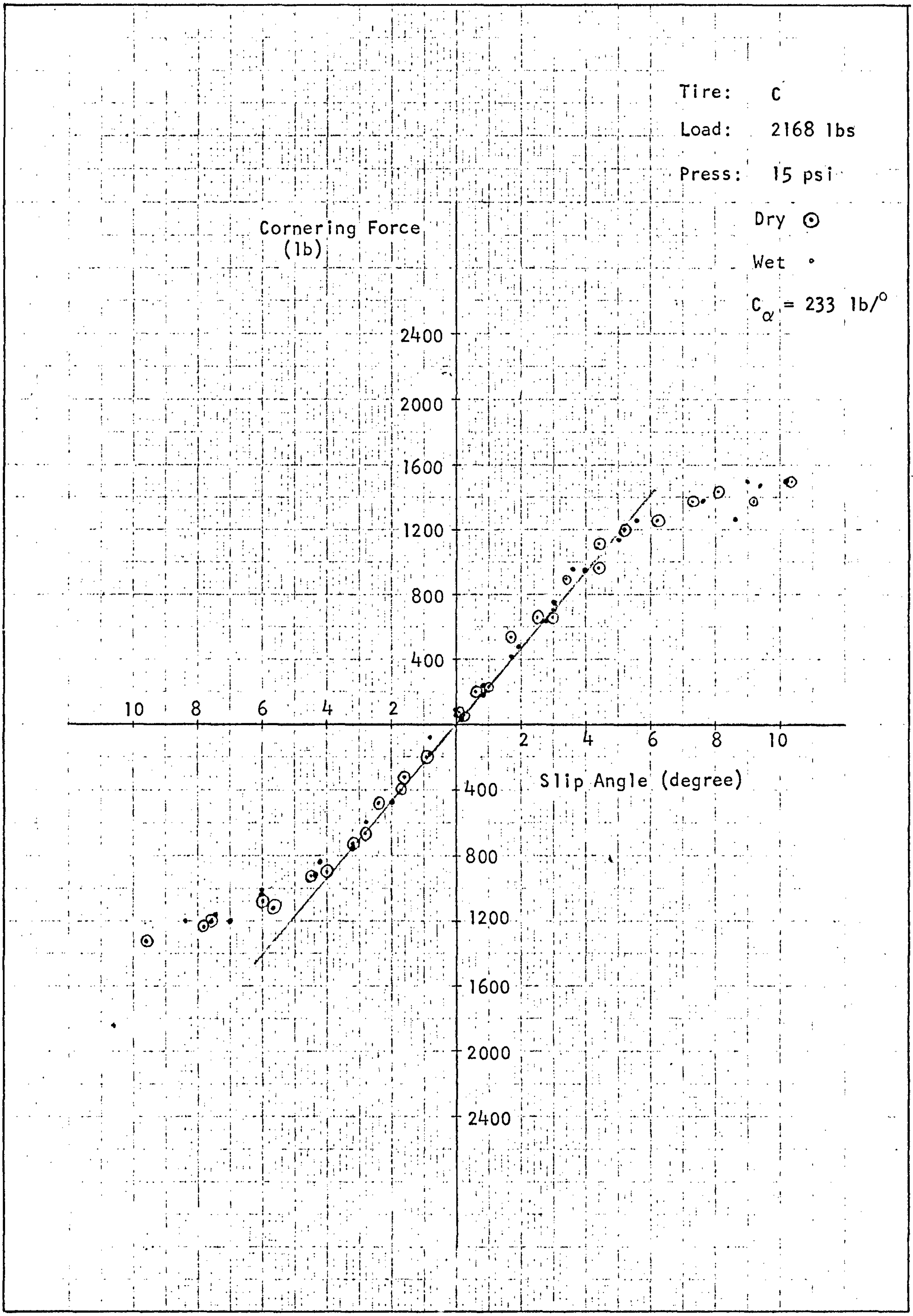


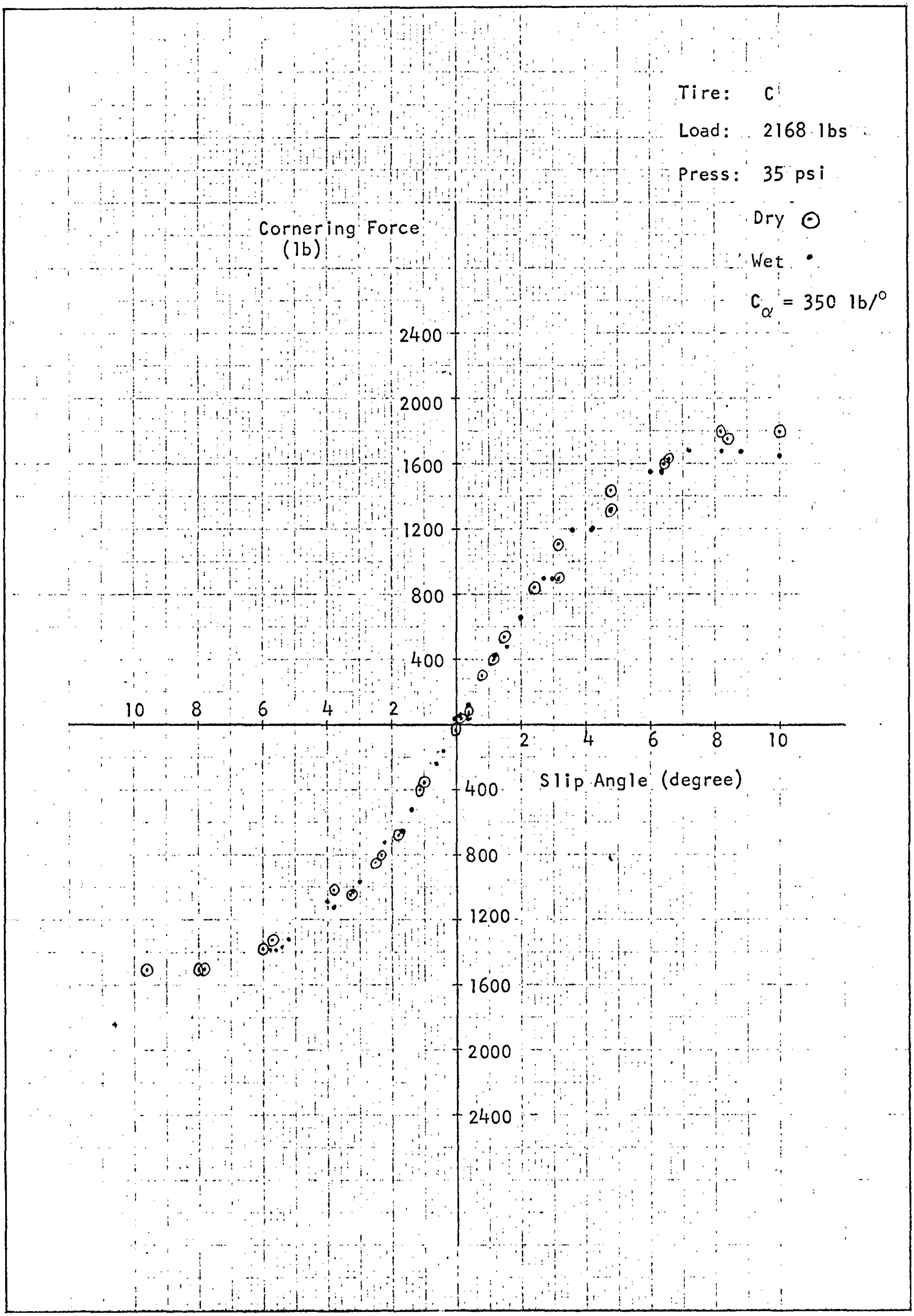
Tire: B
Load: 3350 lb
Press: 50 psi
Dry
Wet
C_α = 420 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

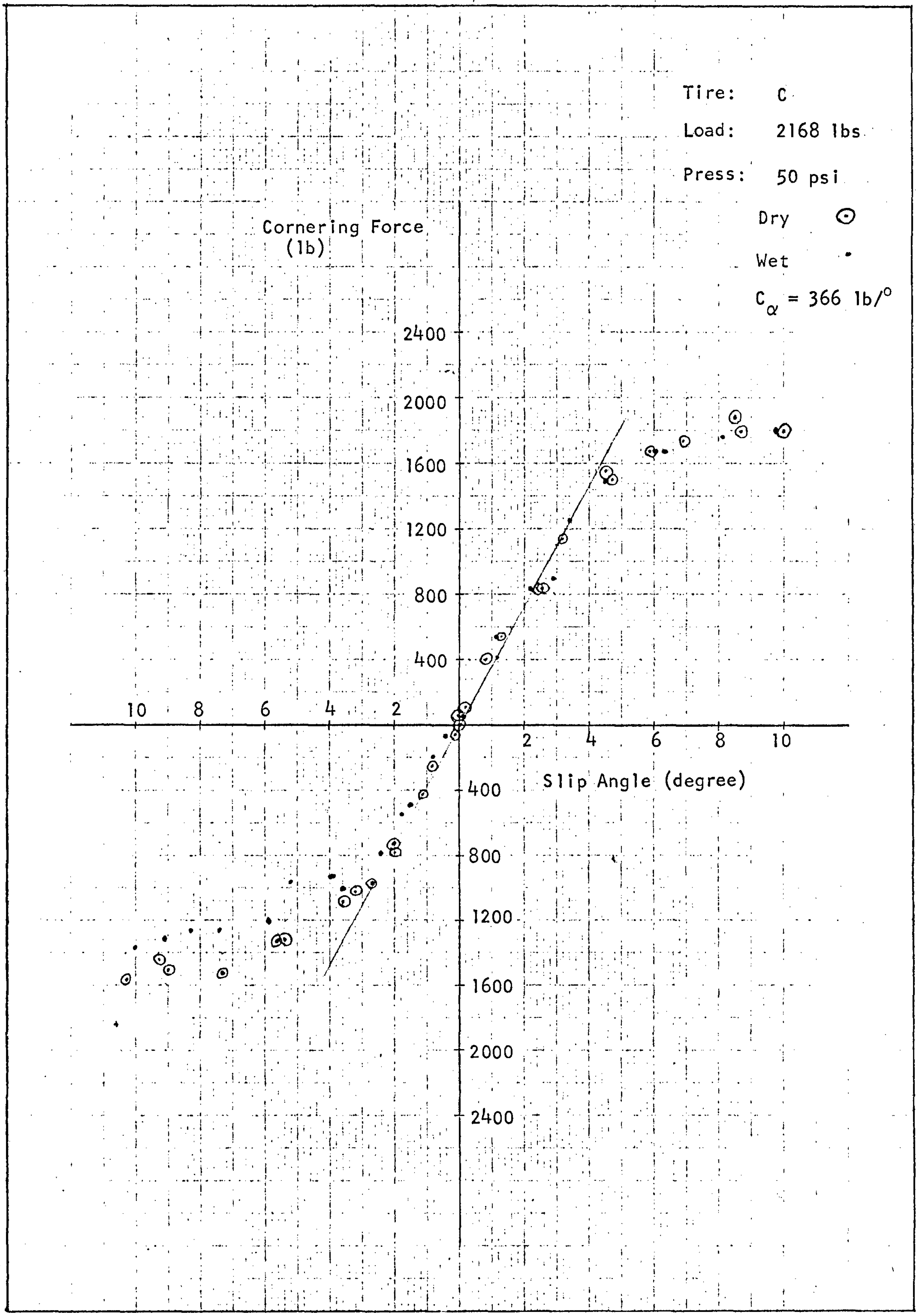

Tire: C
Load: 1504 lbs
Press: 15 psi
Dry
Wet
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)


Tire: C
Load: 1504 lbs
Press: 35 psi
Dry ⊙
Wet •
C_α = 267 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

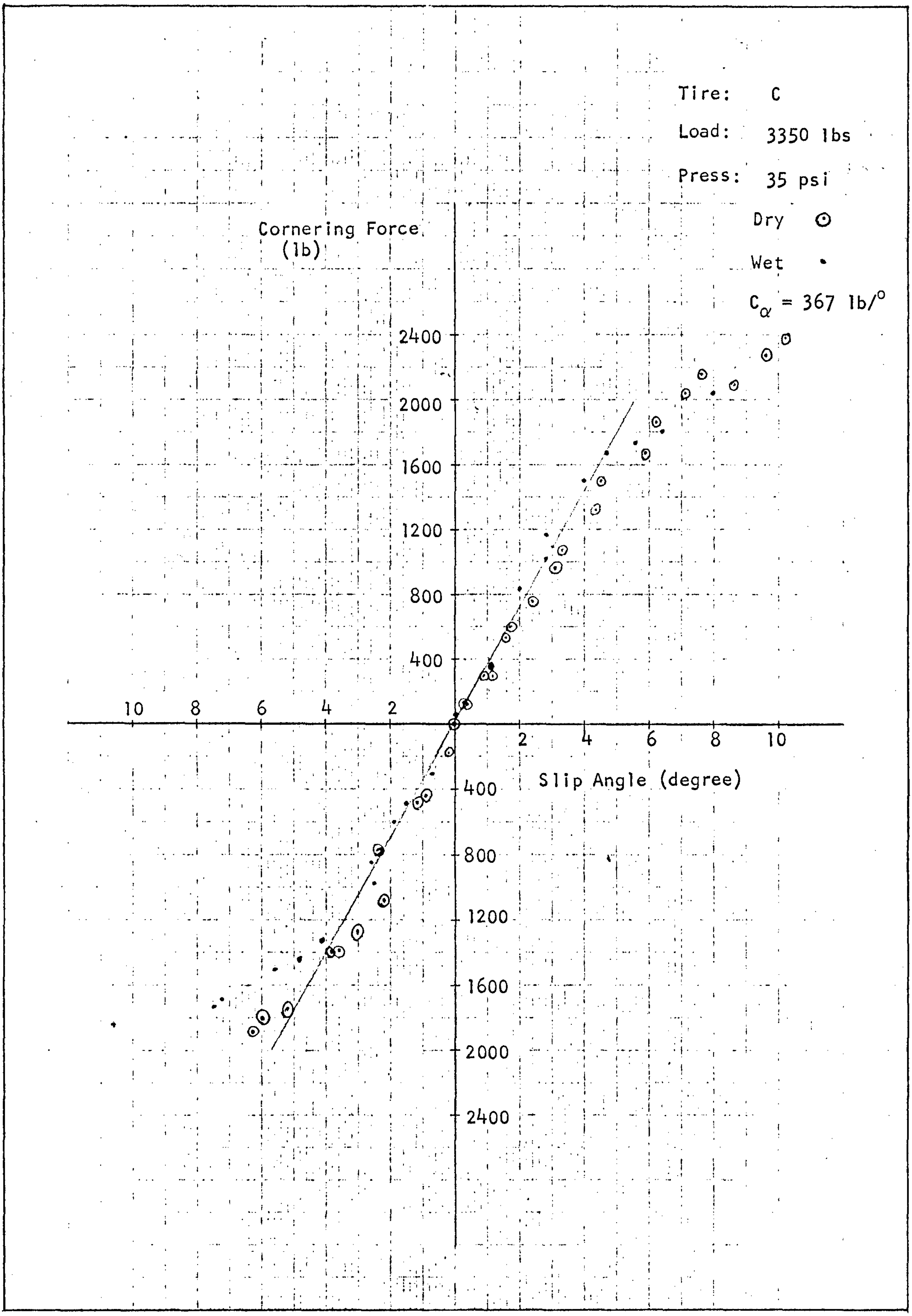

Tire: C
Load: 1504 lbs
Press: 50 psi
Dry ⊙
Wet •
C_α = 200 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

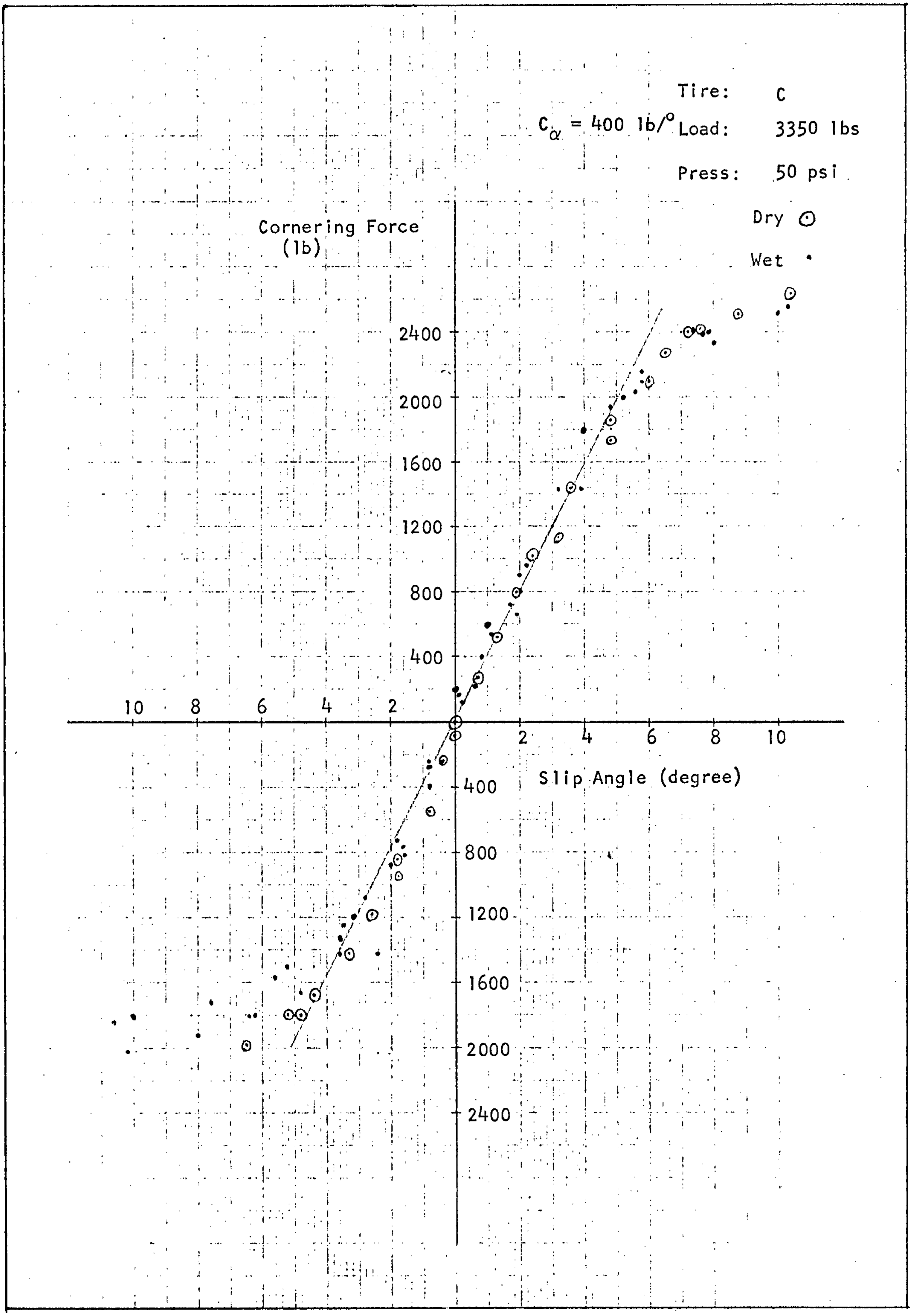

Tire: C
Load: 2168 lbs
Press: 15 psi
Dry ⊙
Wet •
C_α = 233 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

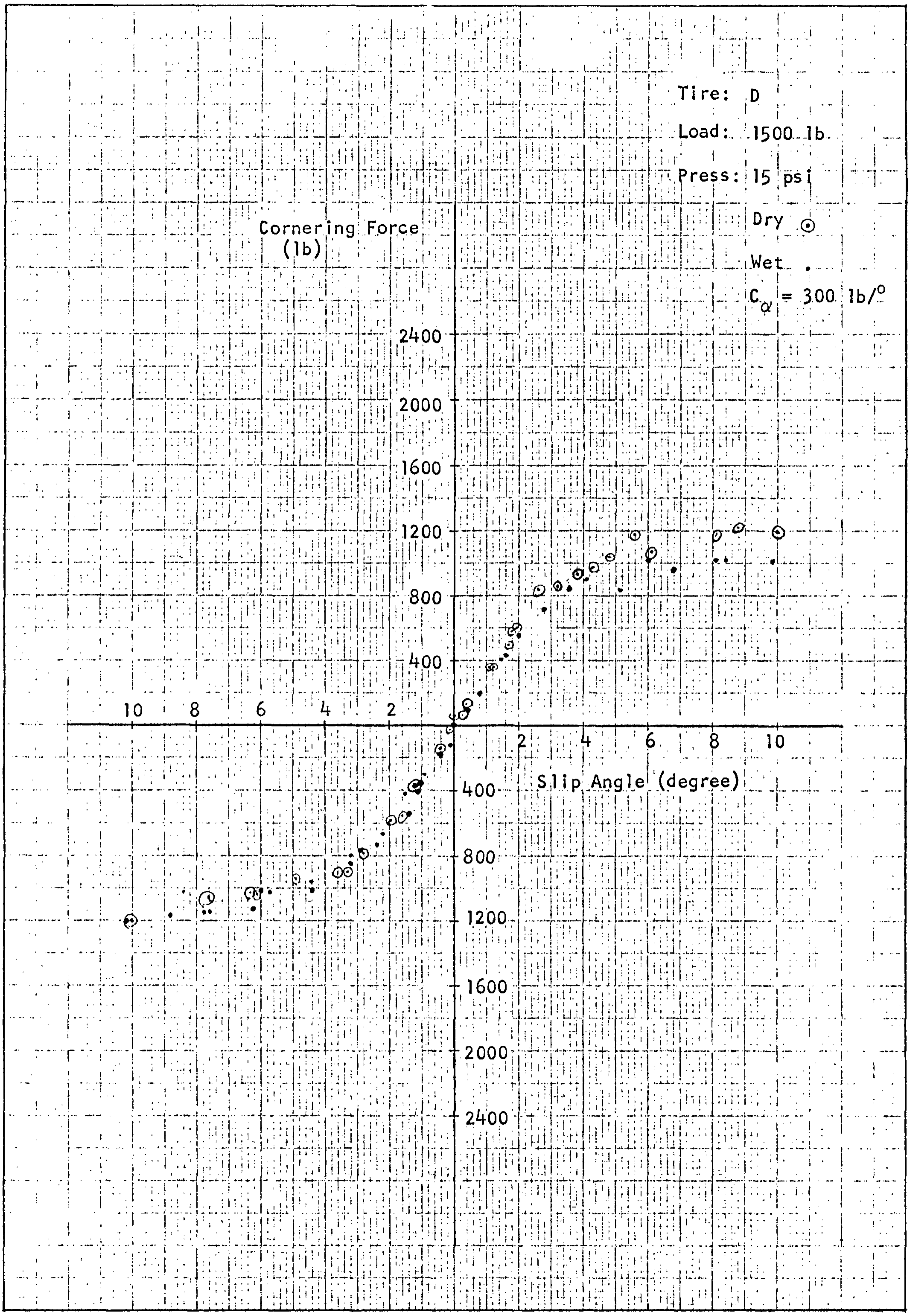

Tire: C
Load: 2168 lbs
Press: 35 psi
Dry
Wet
C_α = 350 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
0
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

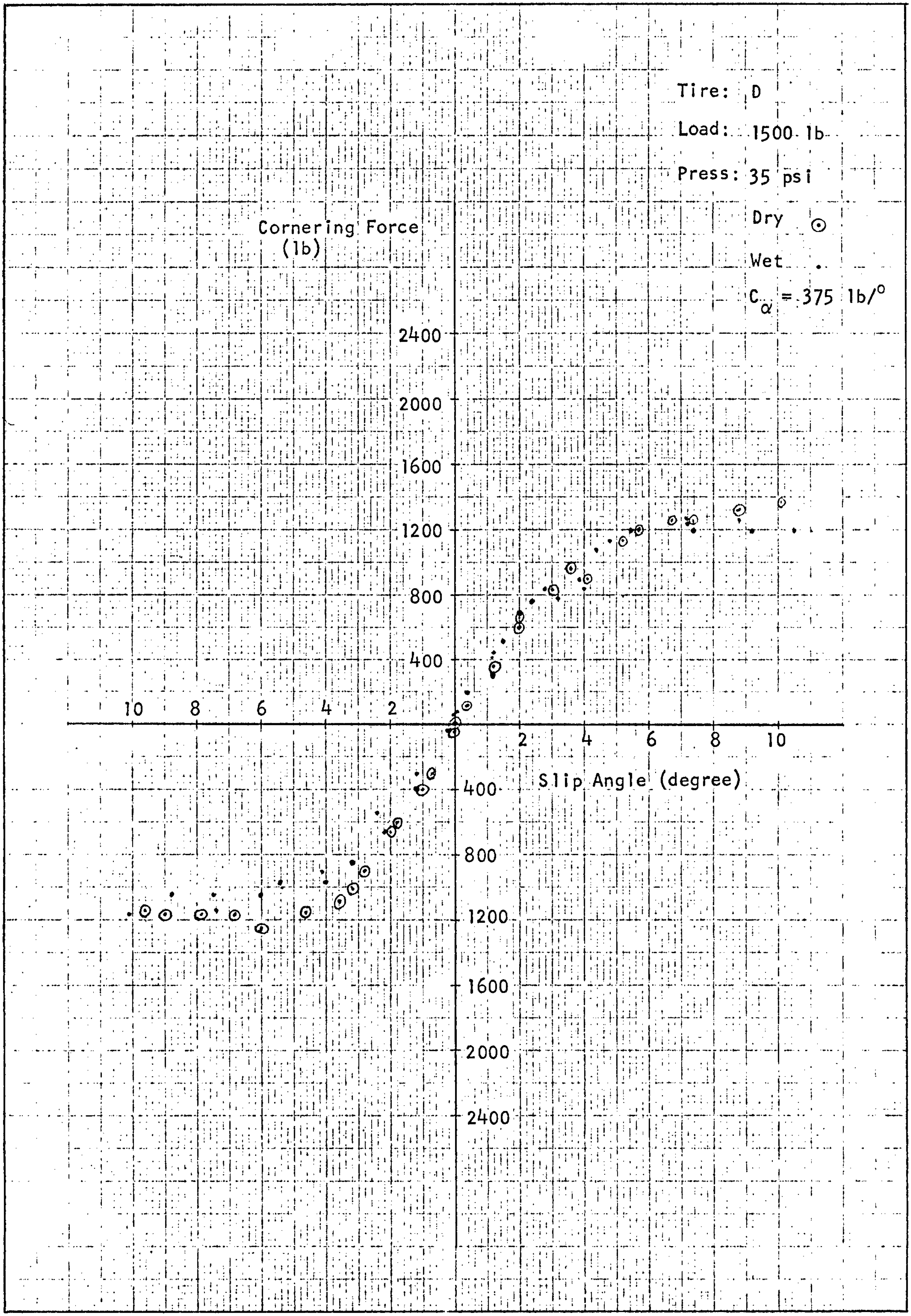


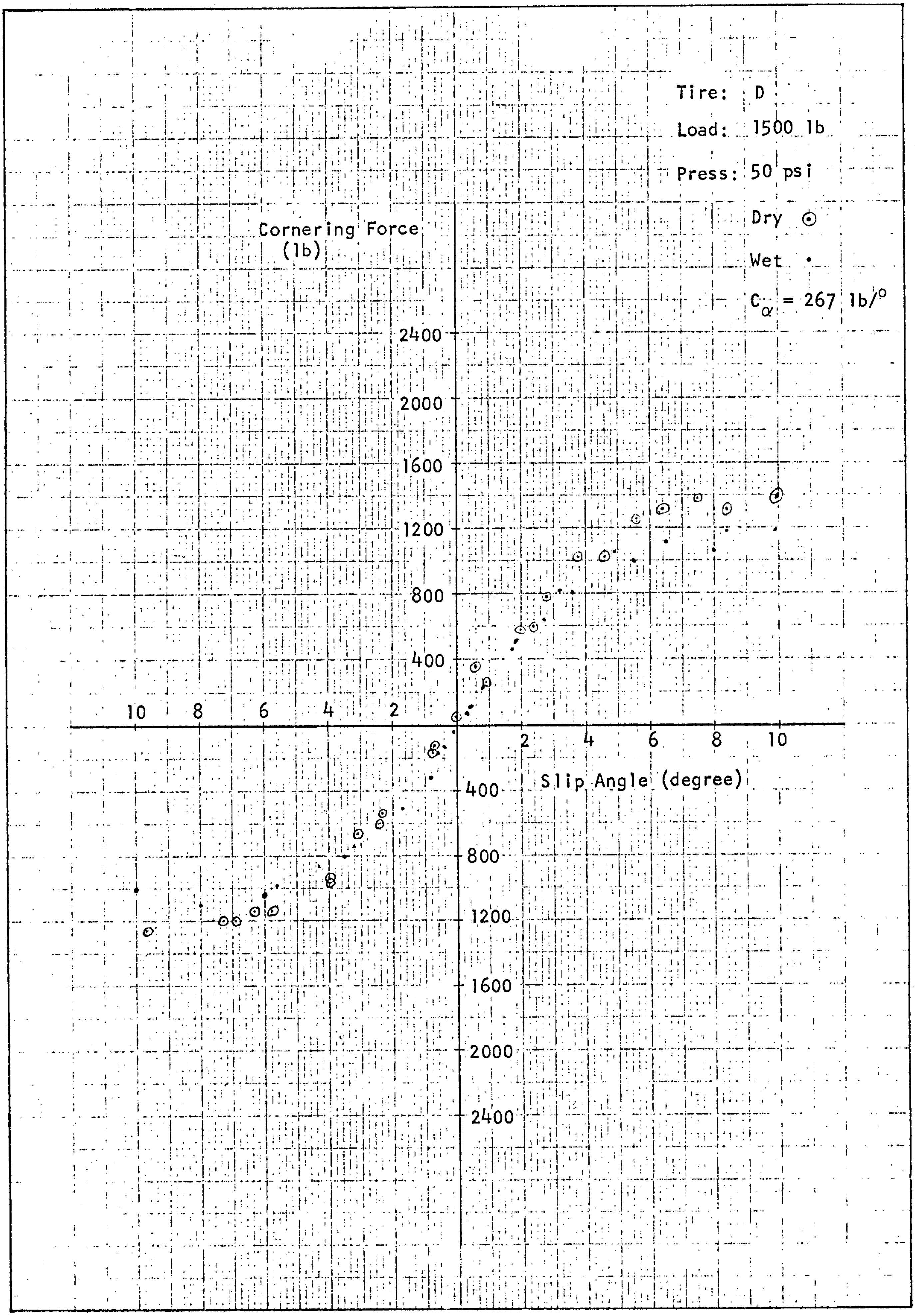
Tire: C
Load: 2168 lbs
Press: 50 psi
Dry
Wet
C_α = 366 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

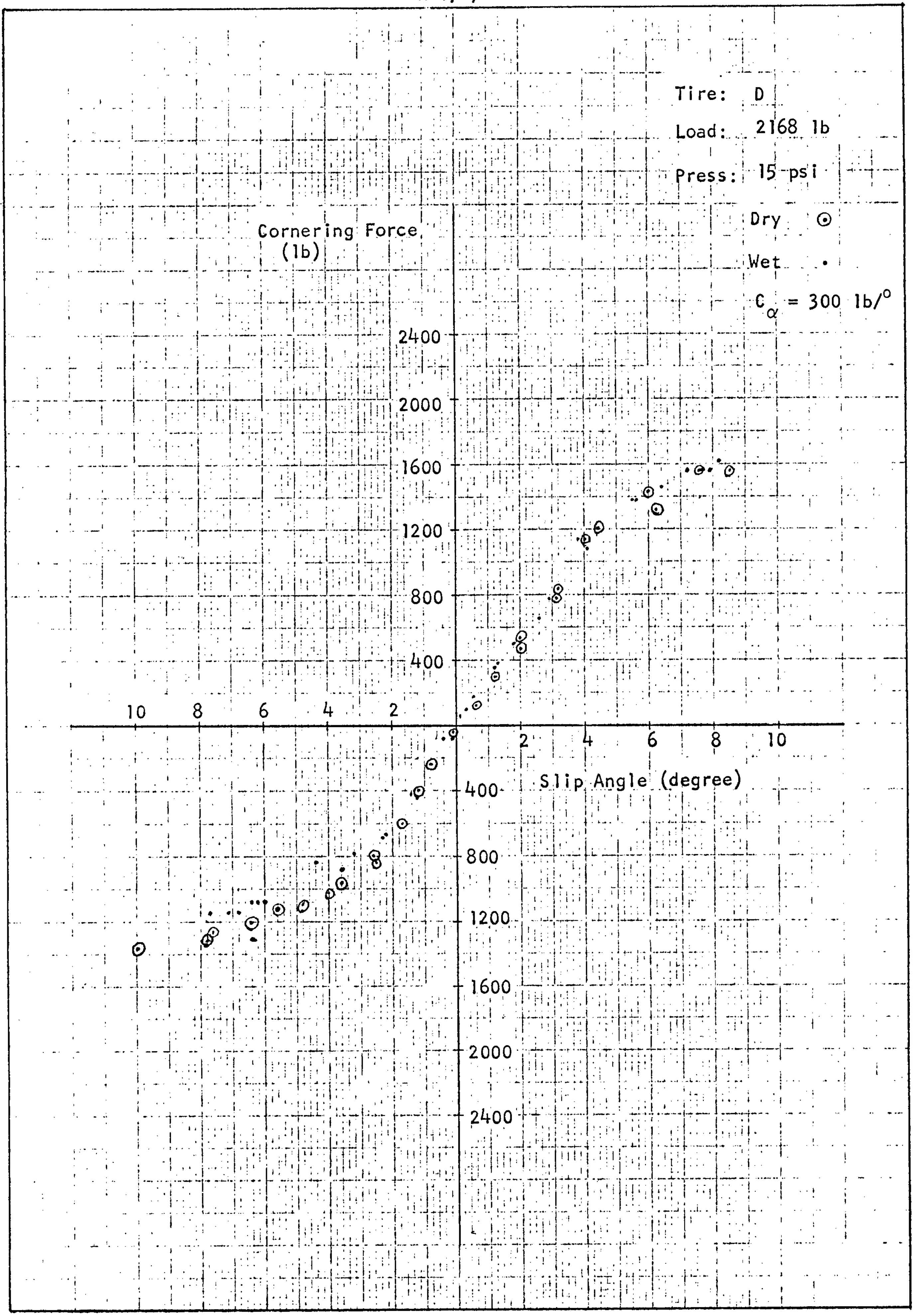

Tire: C
Load: 3350 lbs
Press: 35 psi
Dry
Wet
C_α = 367 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: C
C_α = 400 lb/° Load: 3350 lbs
Press: 50 psi
Dry ⊙
Wet •
Cornering Force (lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400

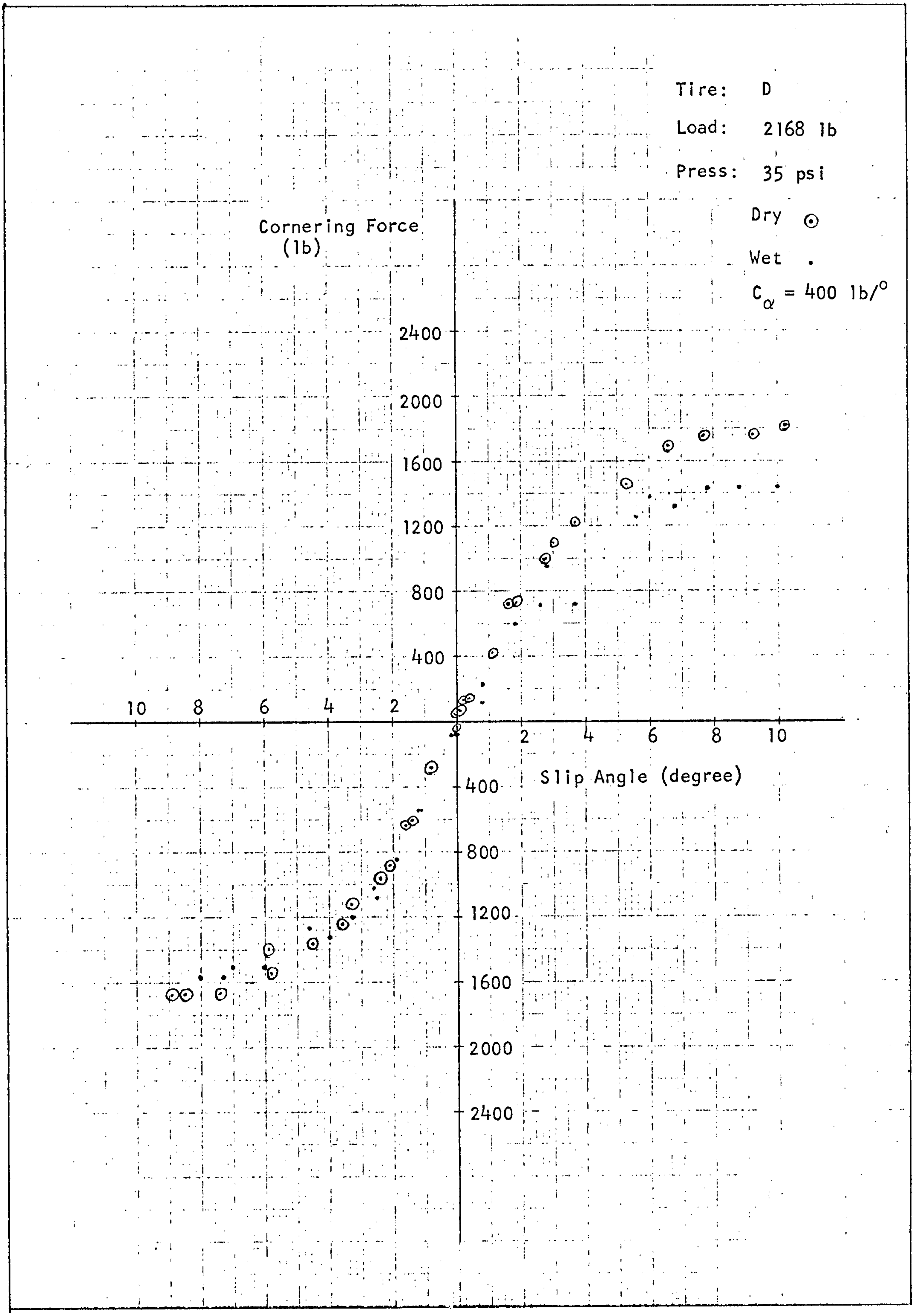

Tire: D
Load: 1500 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

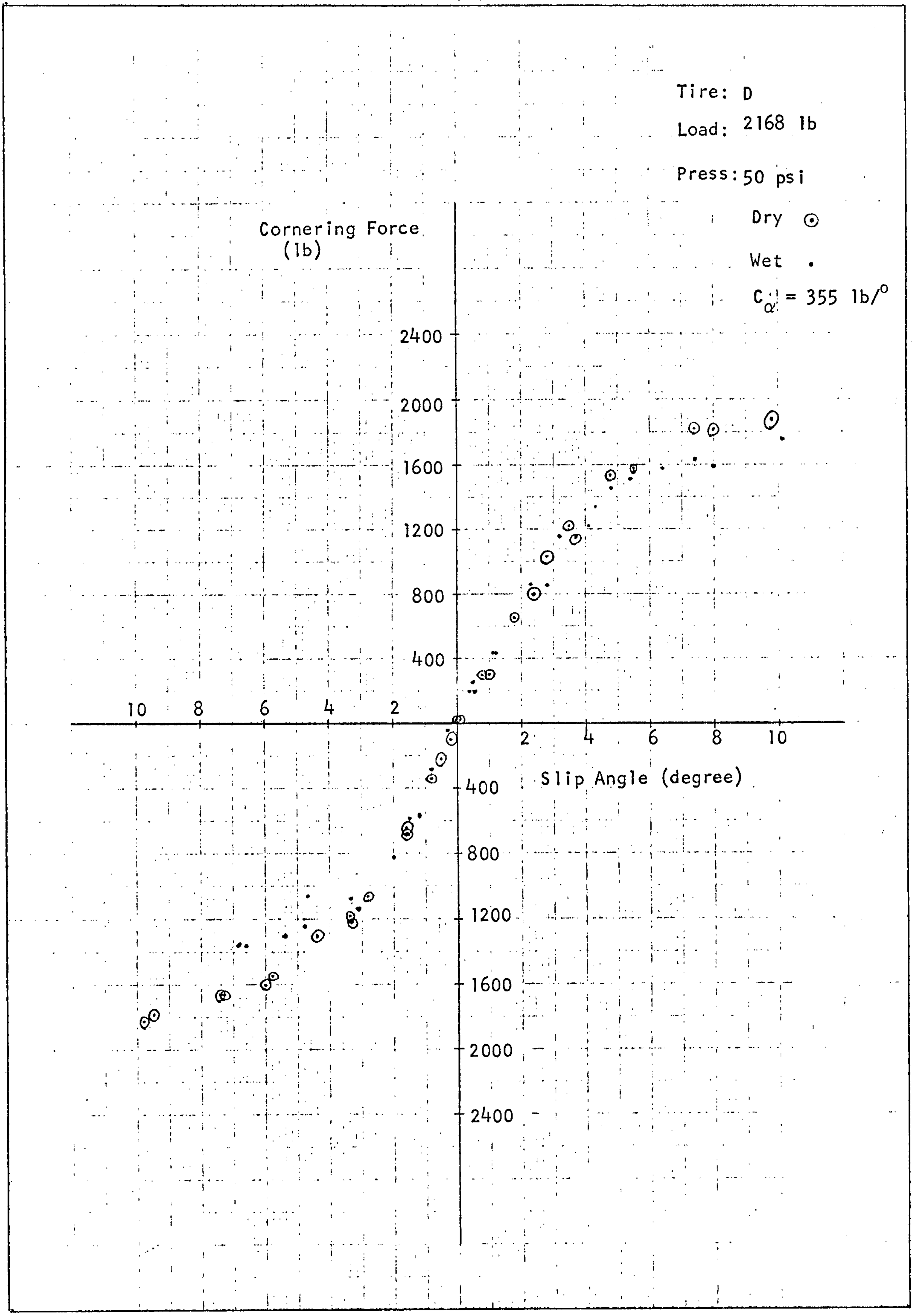

Tire: D
Load: 1500 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 375 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

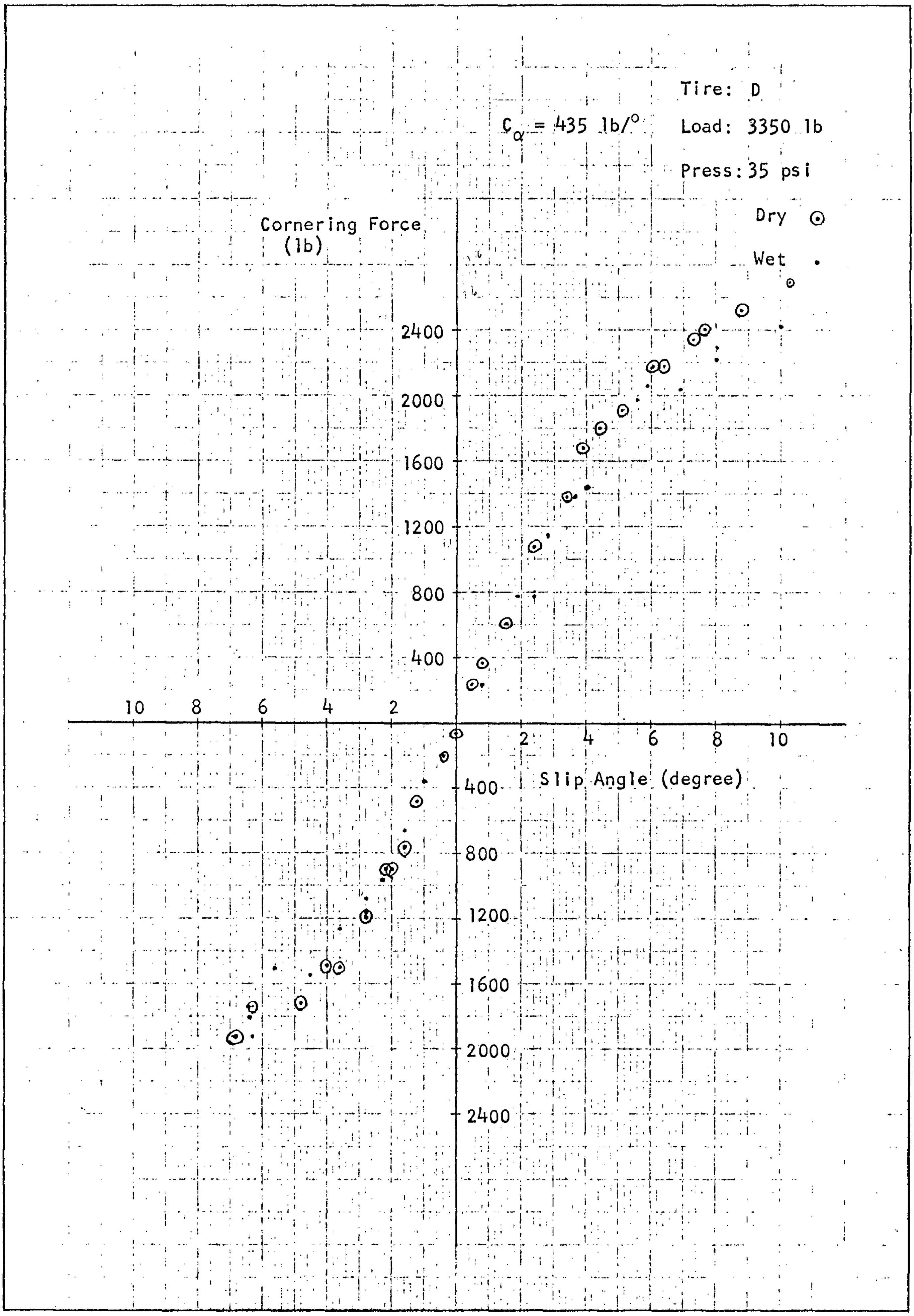

Tire: D
Load: 1500 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 267 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400

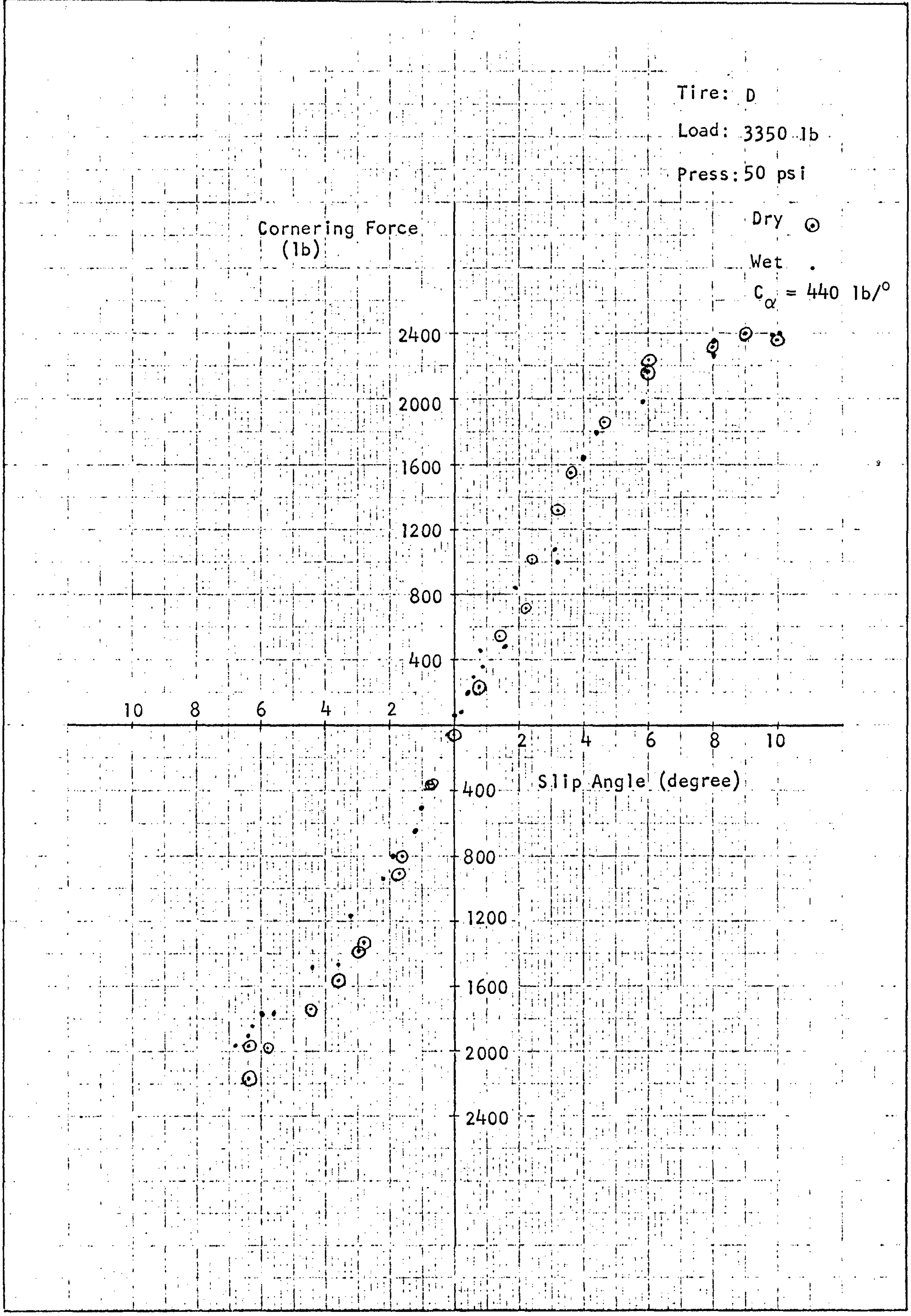


Tire: D
Load: 2168 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

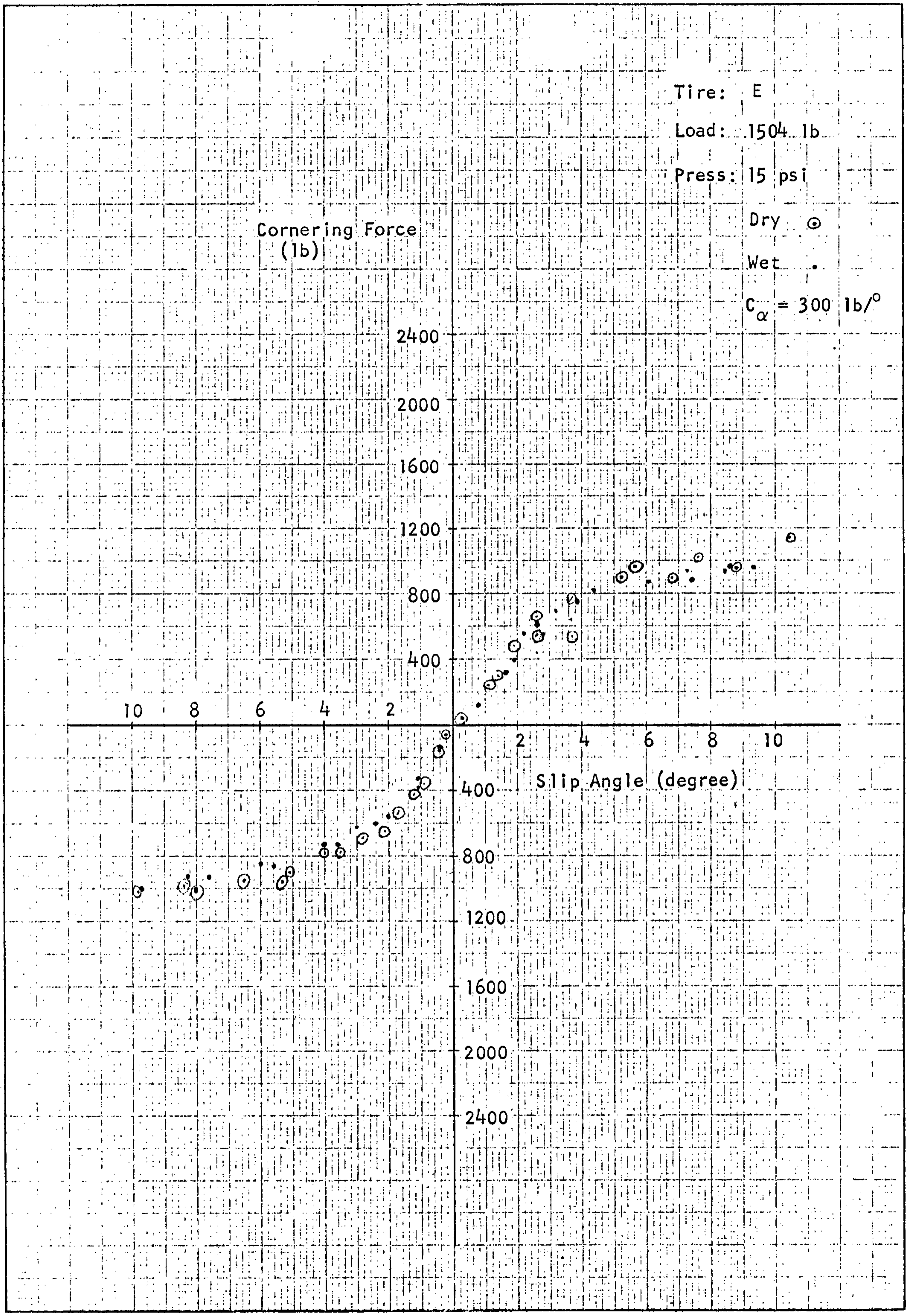

Tire: D
Load: 2168 lb
Press: 35 psi
Dry ⊙
Wet .
C_α = 400 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

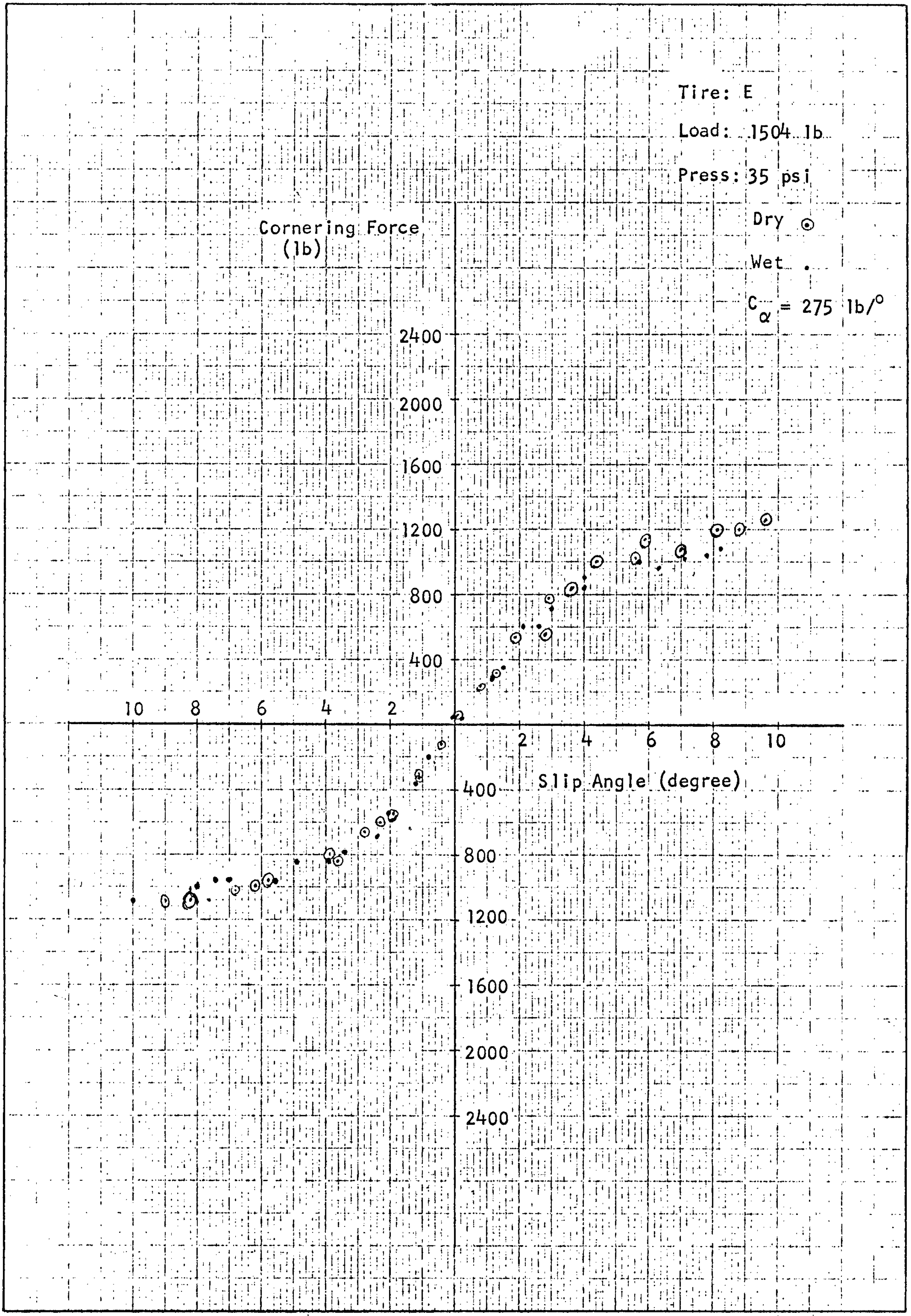

Tire: D
Load: 2168 lb
Press: 50 psi
Dry ⊙
Wet •
$C_{\alpha} = 355$ lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
0
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

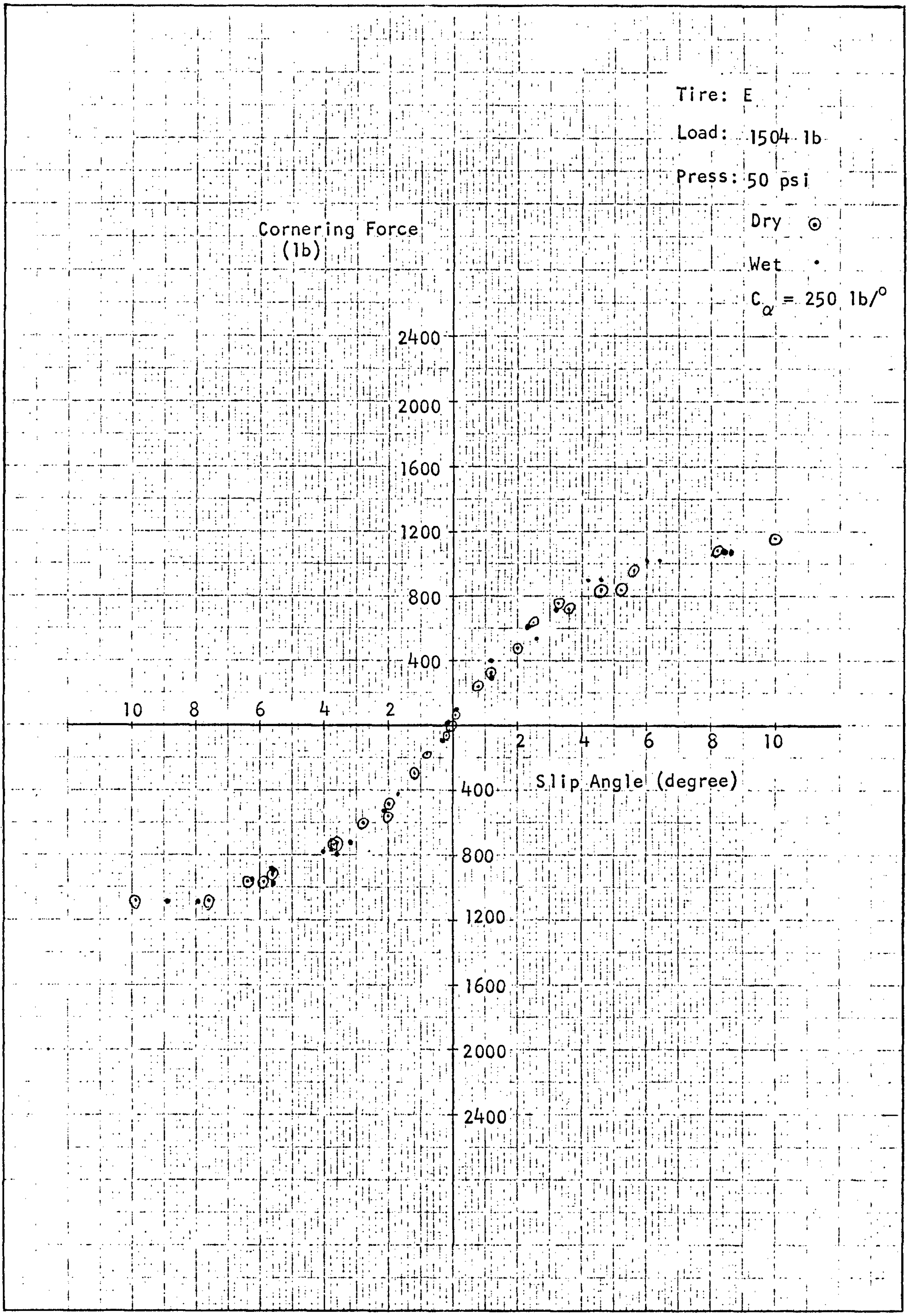

Tire: D
Load: 3350 lb
Press: 35 psi
C_α = 435 lb/°
Dry ⊙
Wet •
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

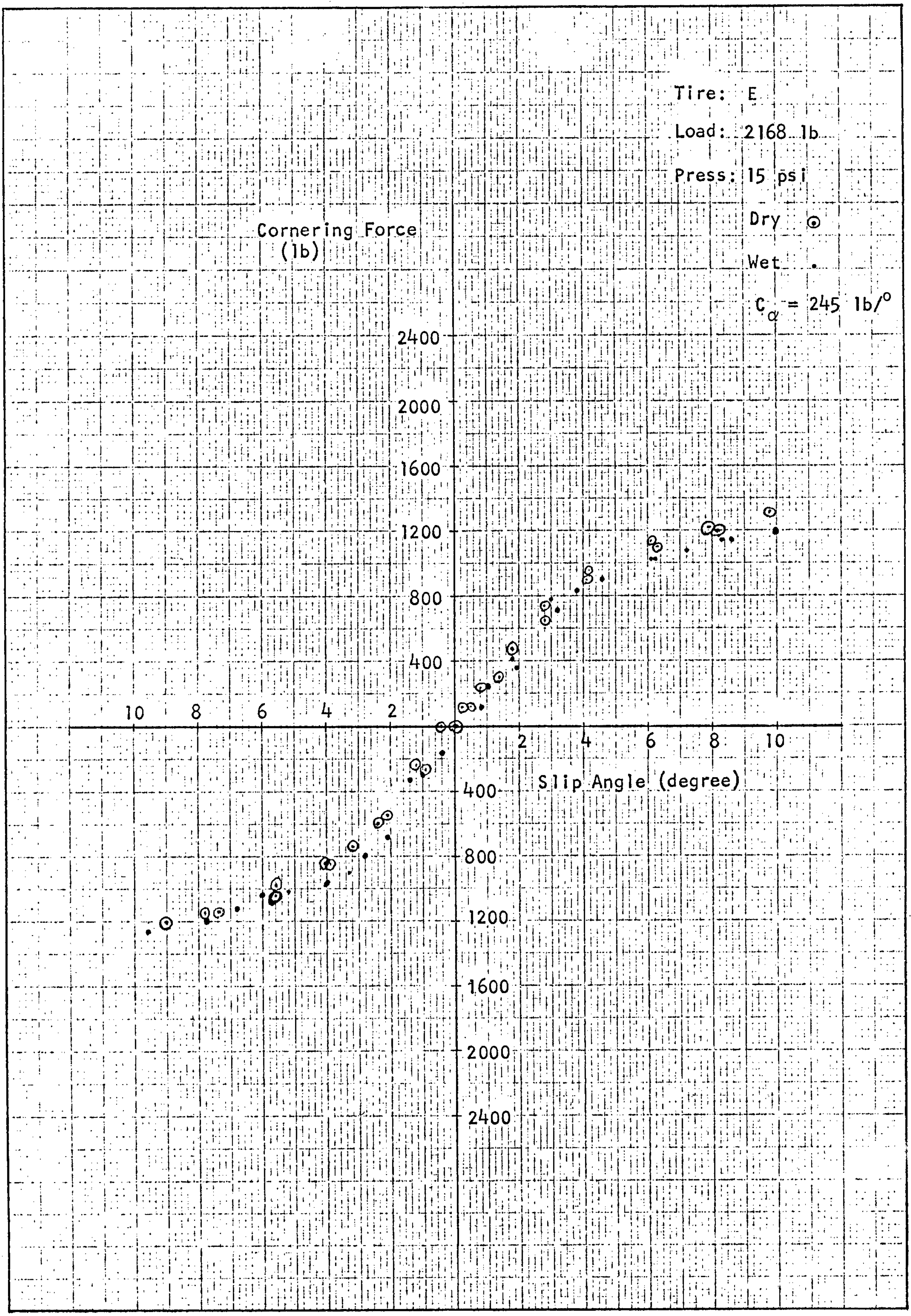


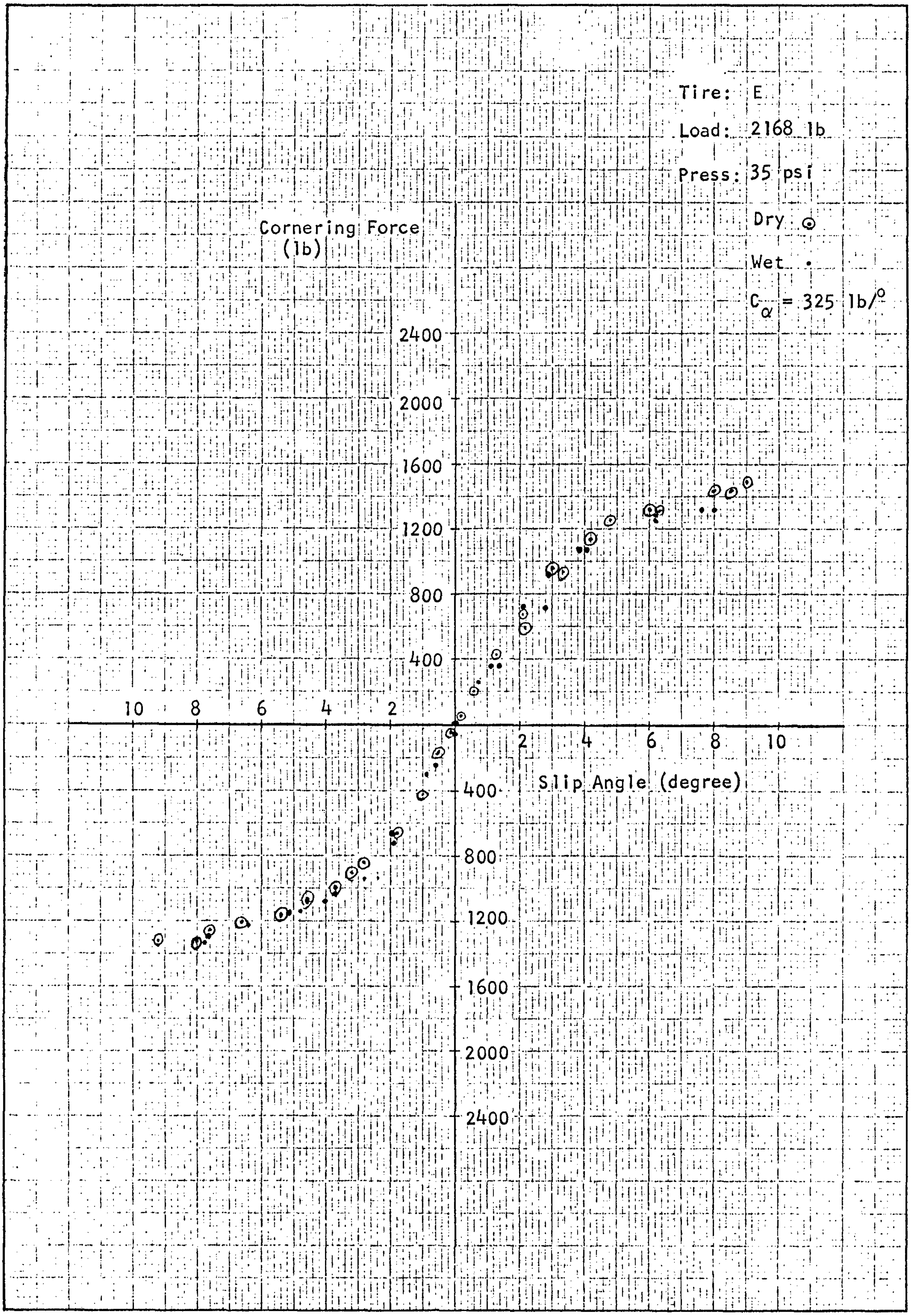
Tire: D
Load: 3350 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 440 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
0
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: E
Load: 1504 lb
Press: 15 psi
Dry
Wet
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

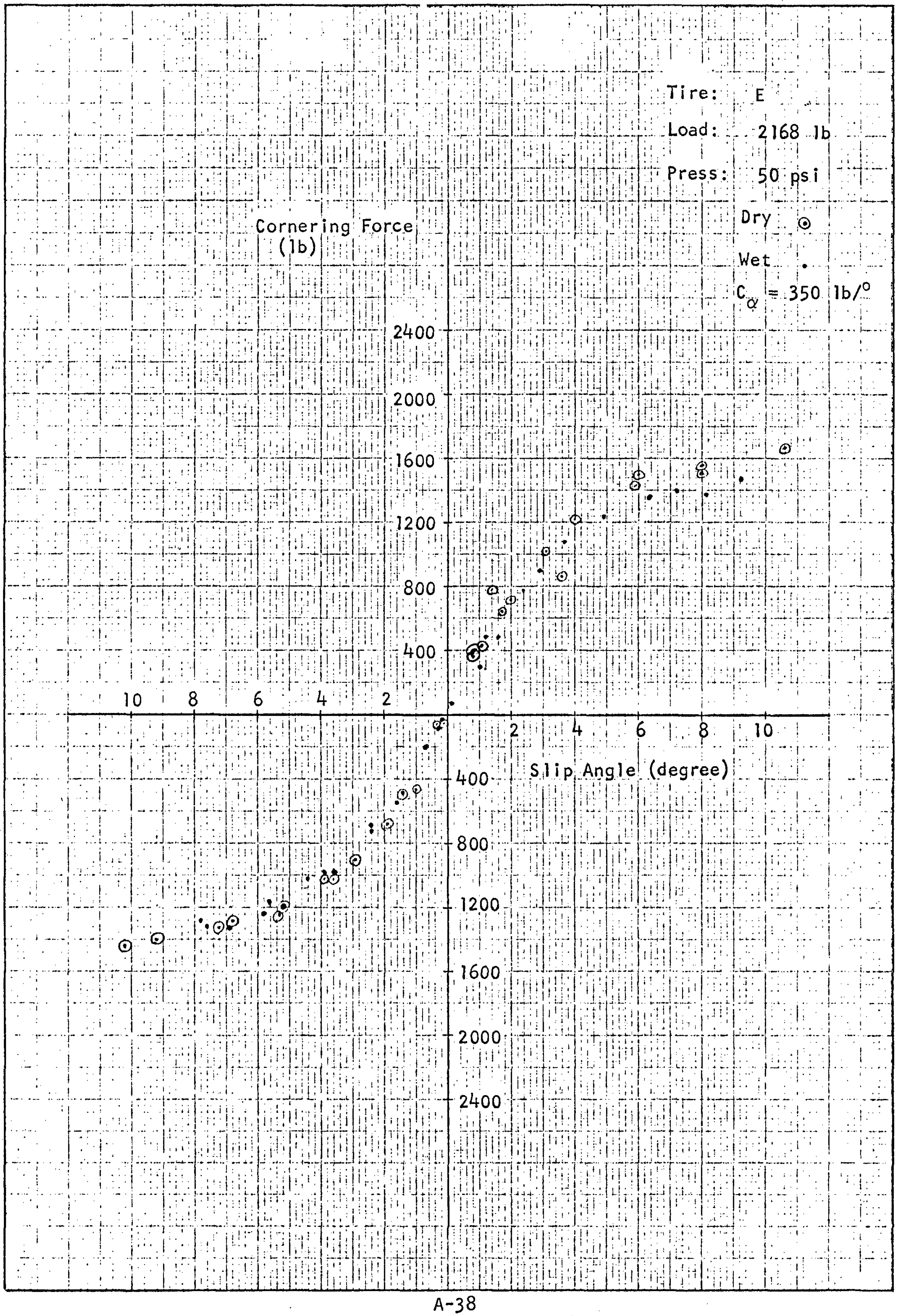

Tire: E
Load: 1504 lb
Press: 35 psi
Dry
Wet
C_α = 275 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

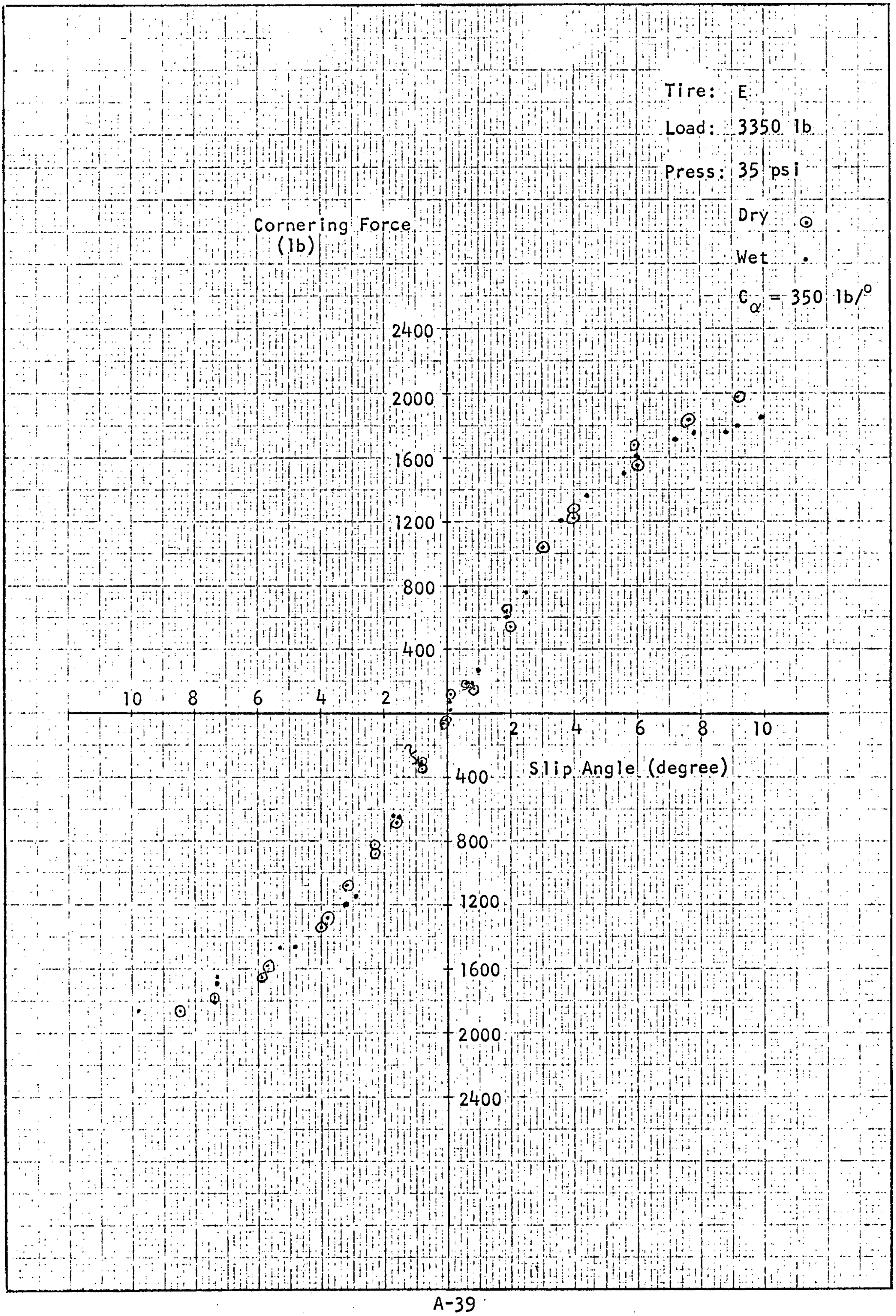

Tire: E
Load: 1504 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

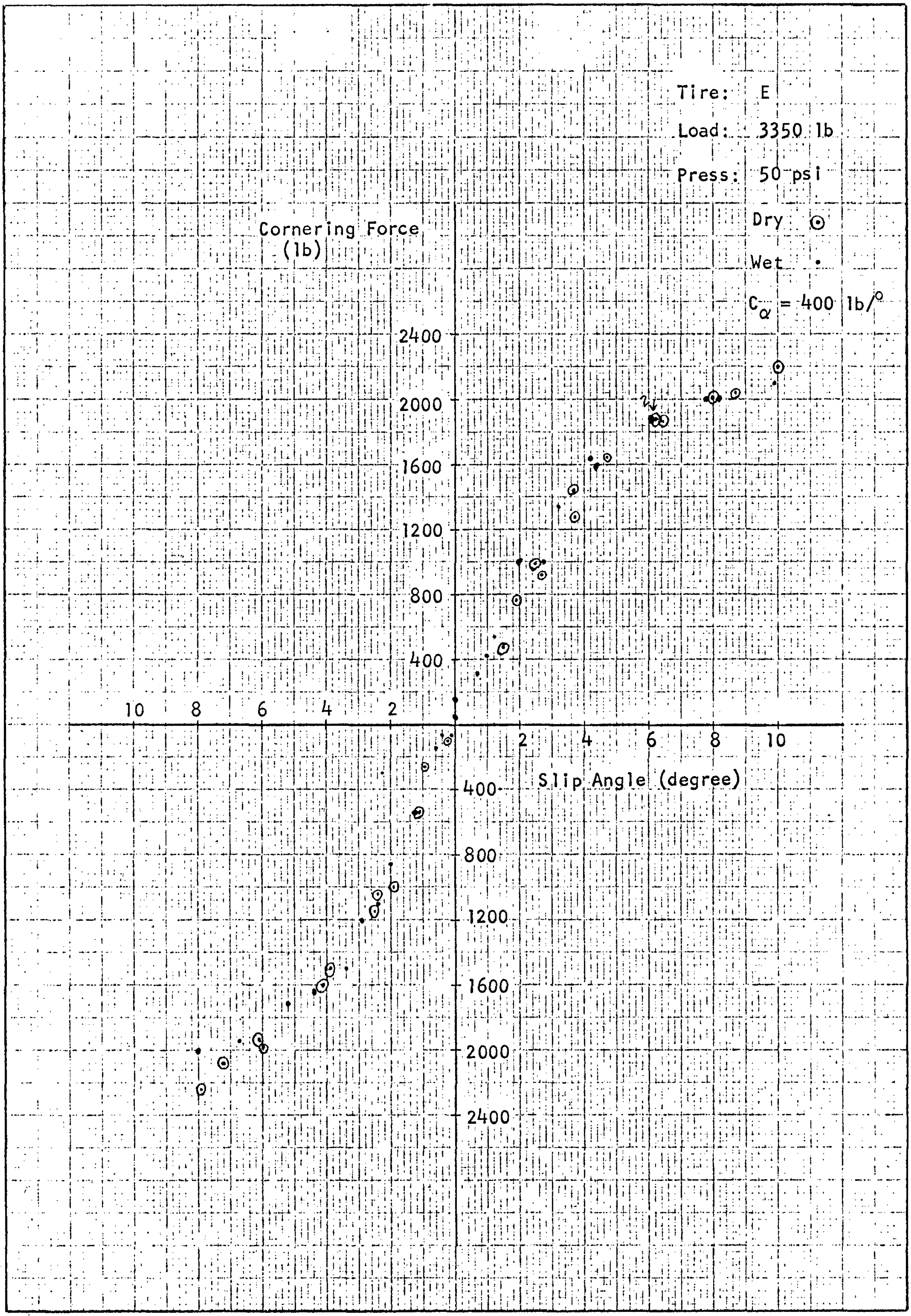

Tire: E
Load: 2168 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 245 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

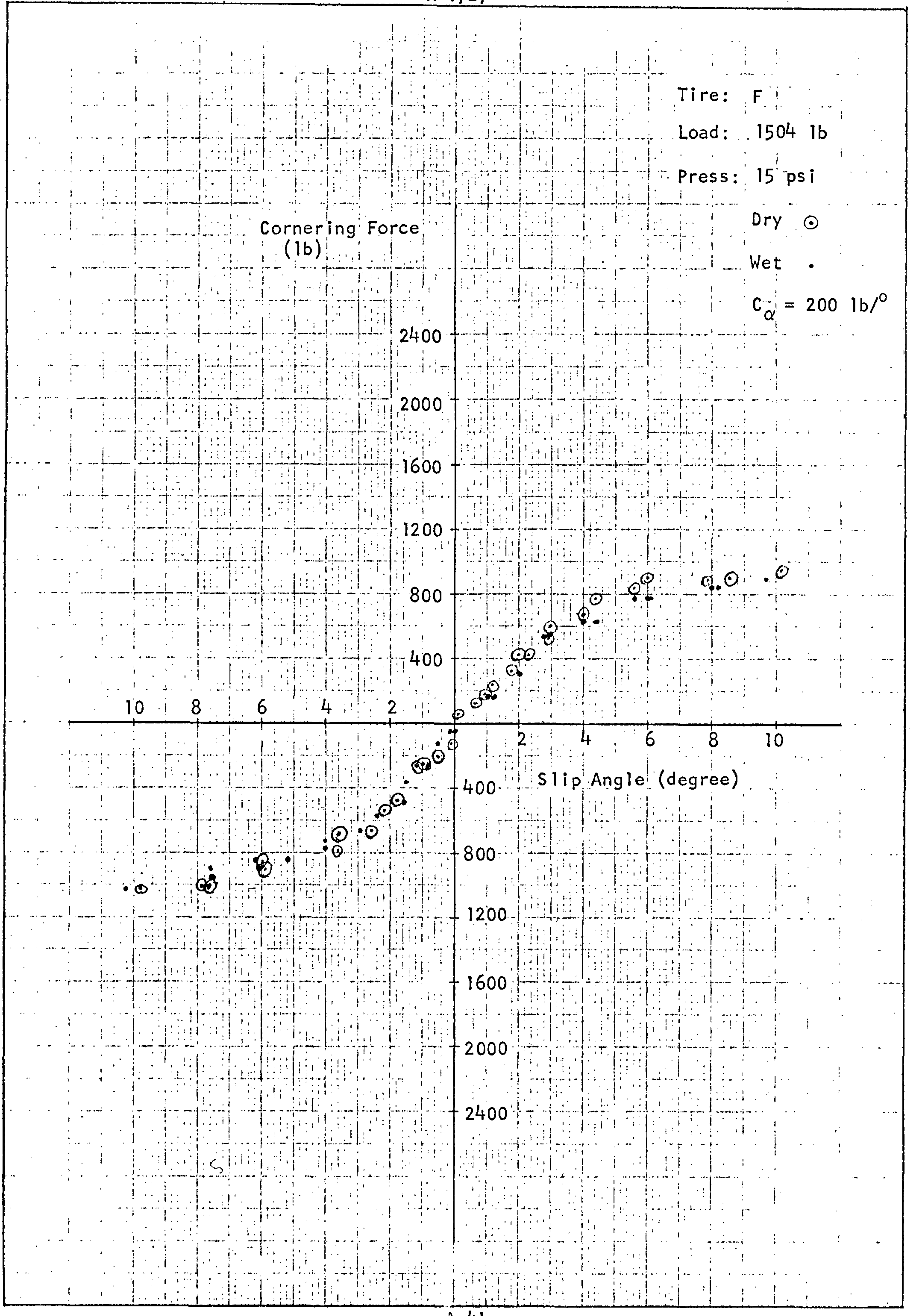


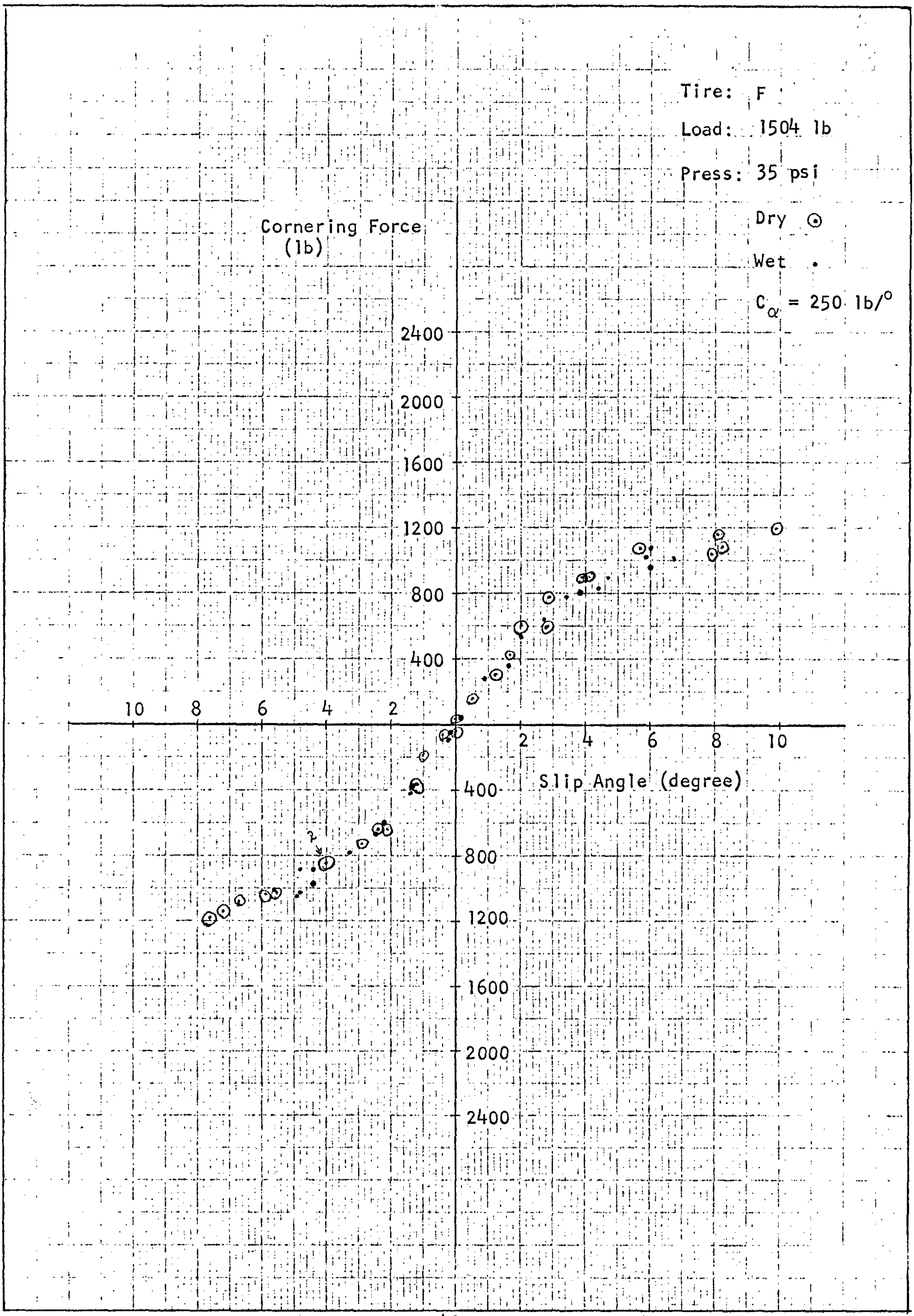
Tire: E
Load: 2168 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 325 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

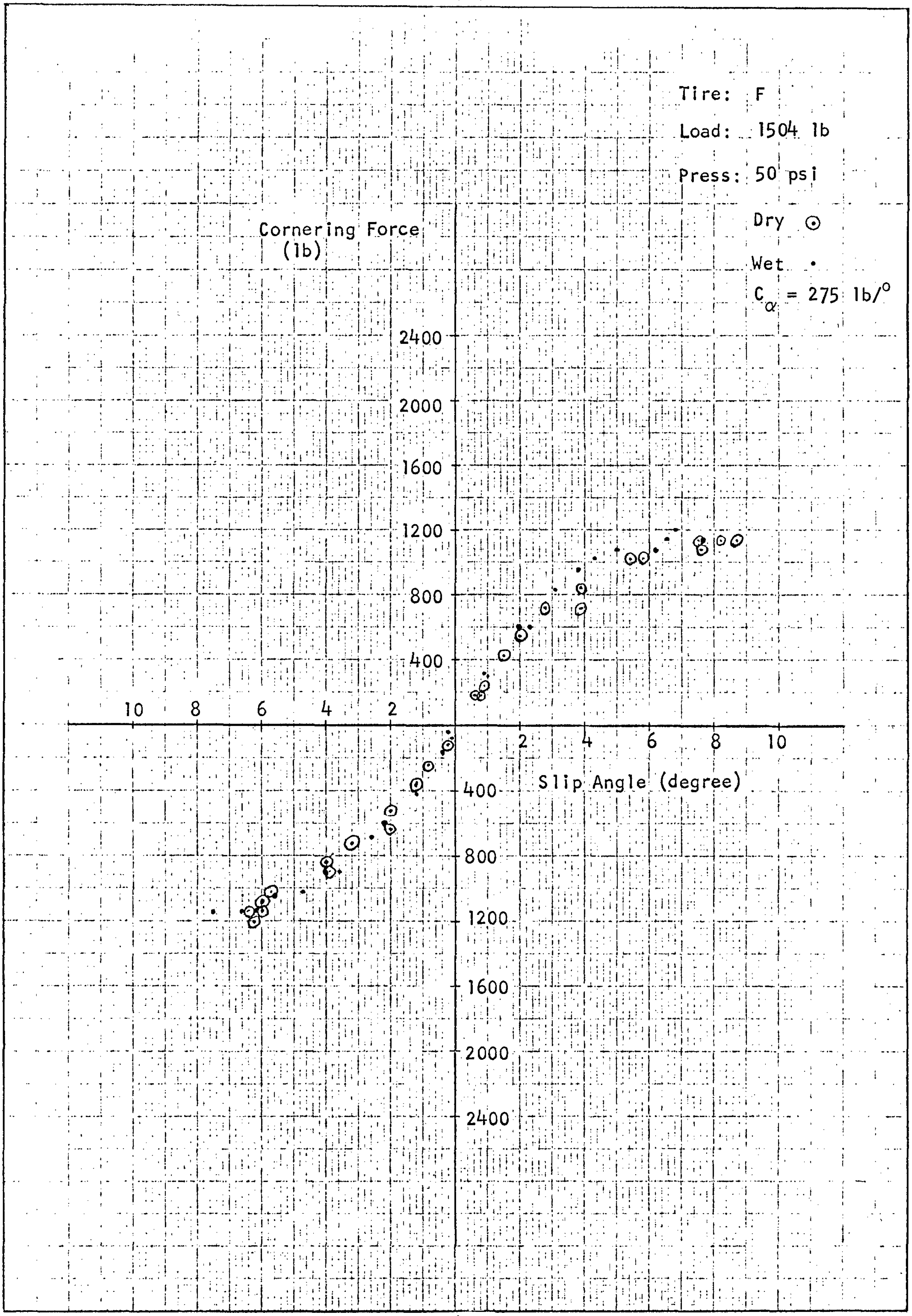

Tire: E
Load: 2168 lb
Press: 50 psi
Dry
Wet
C_α = 350 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

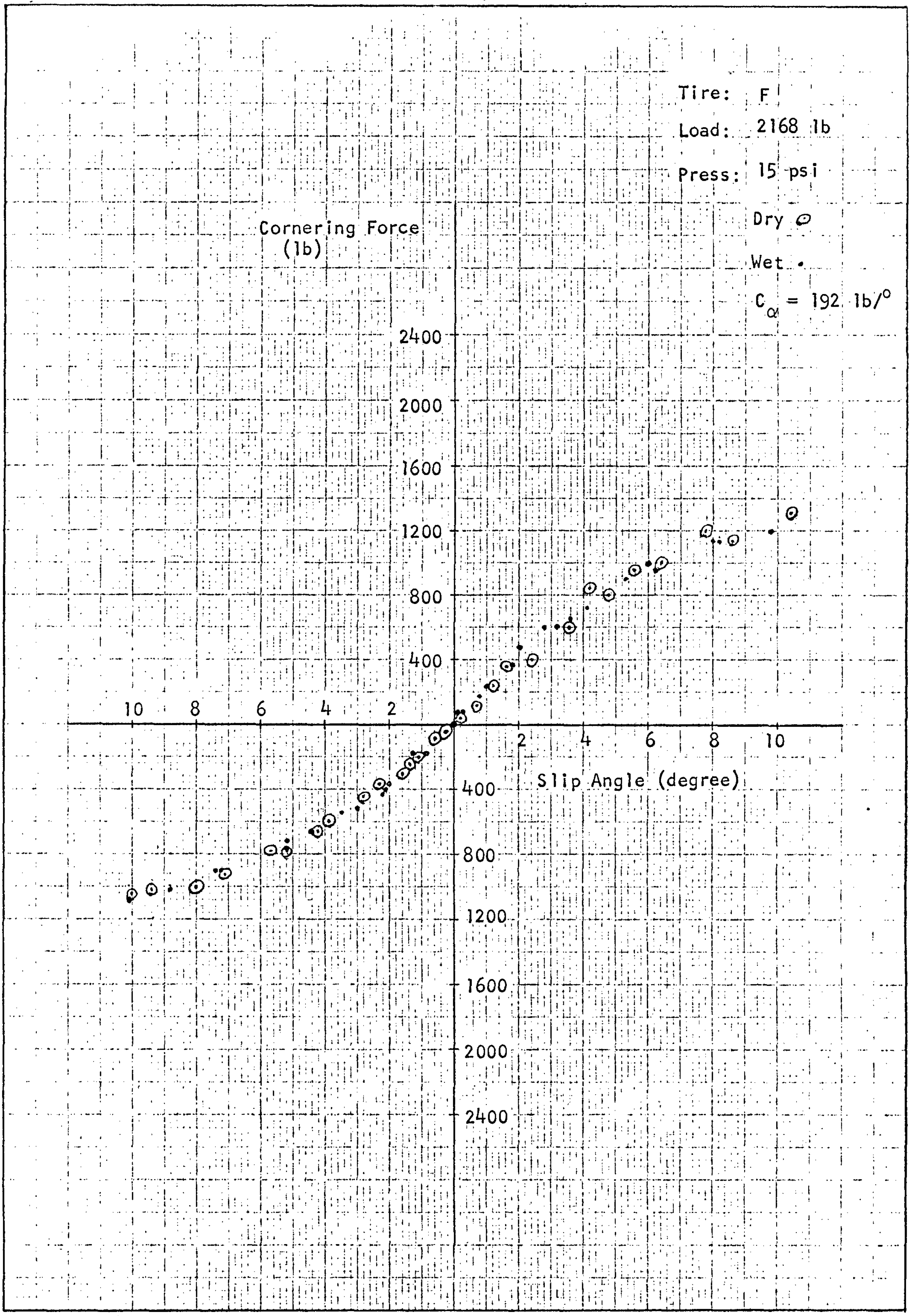

Tire: E
Load: 3350 lb
Press: 35 psi
Dry ⊙
Wet •
$C_\alpha = 350$ lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

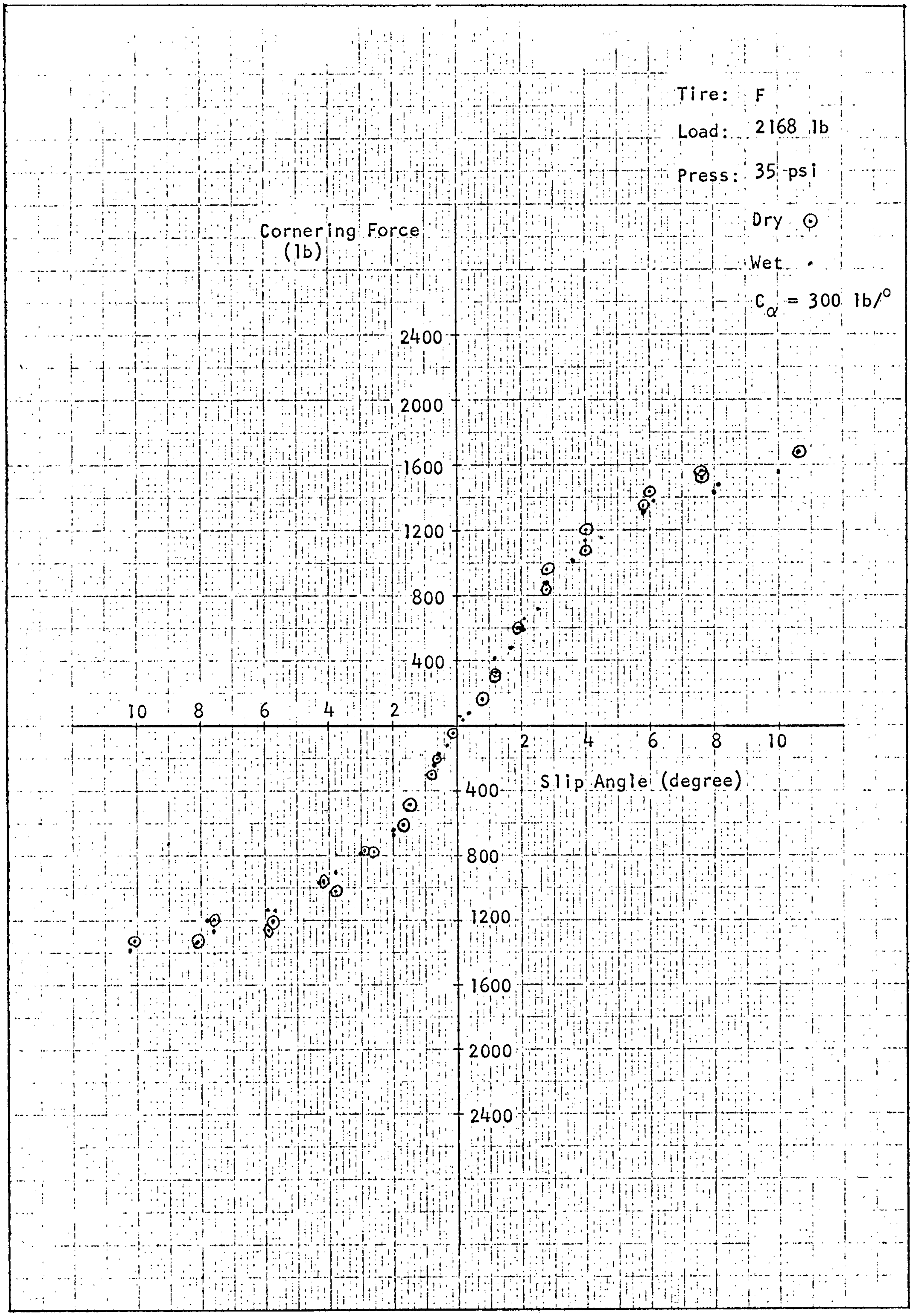

Tire: E
Load: 3350 lb
Press: 50 psi
Dry
Wet
C_α = 400 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

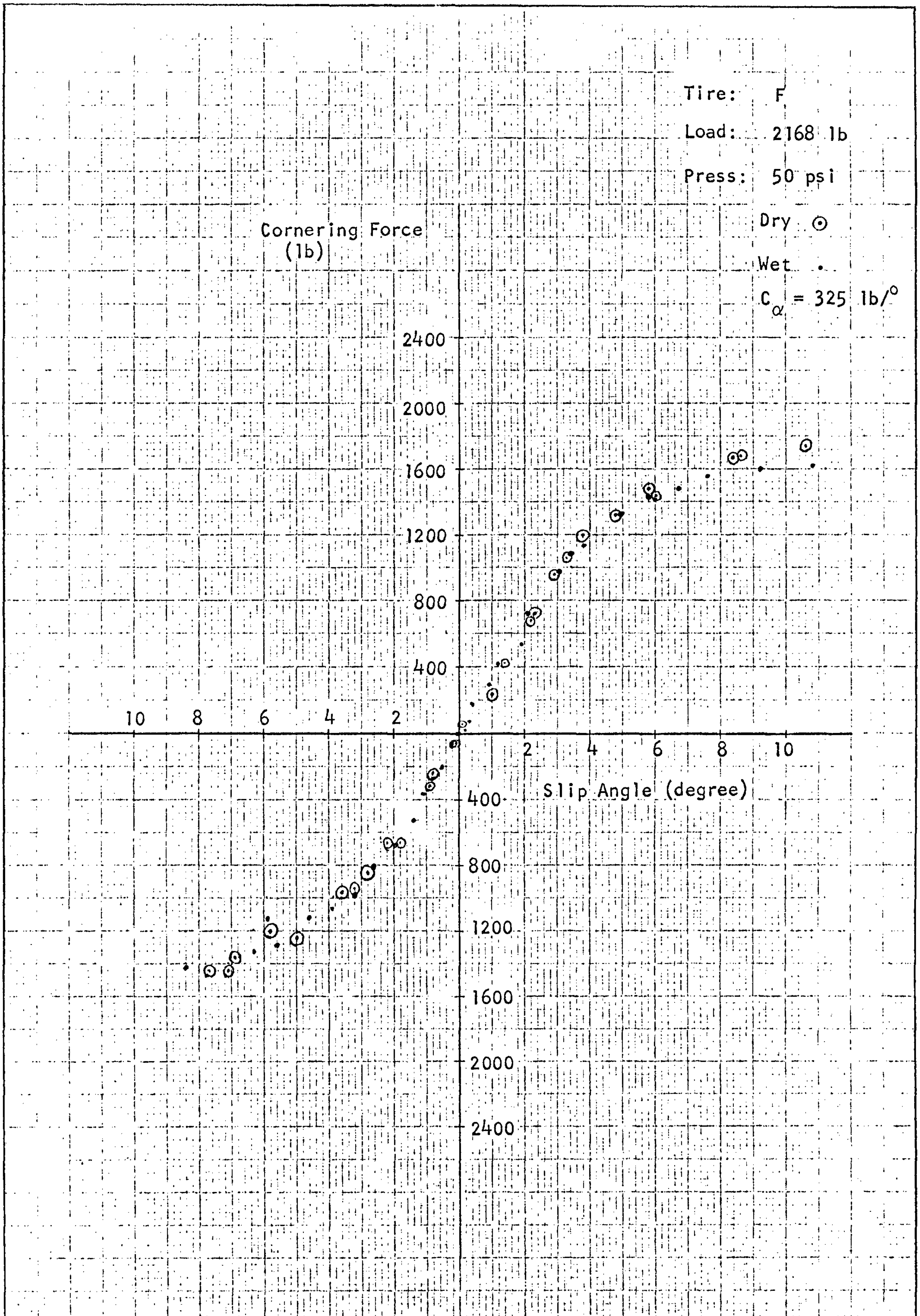

Tire: F
Load: 1504 lb
Press: 15 psi
Dry ⊙
Wet •
C_α = 200 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

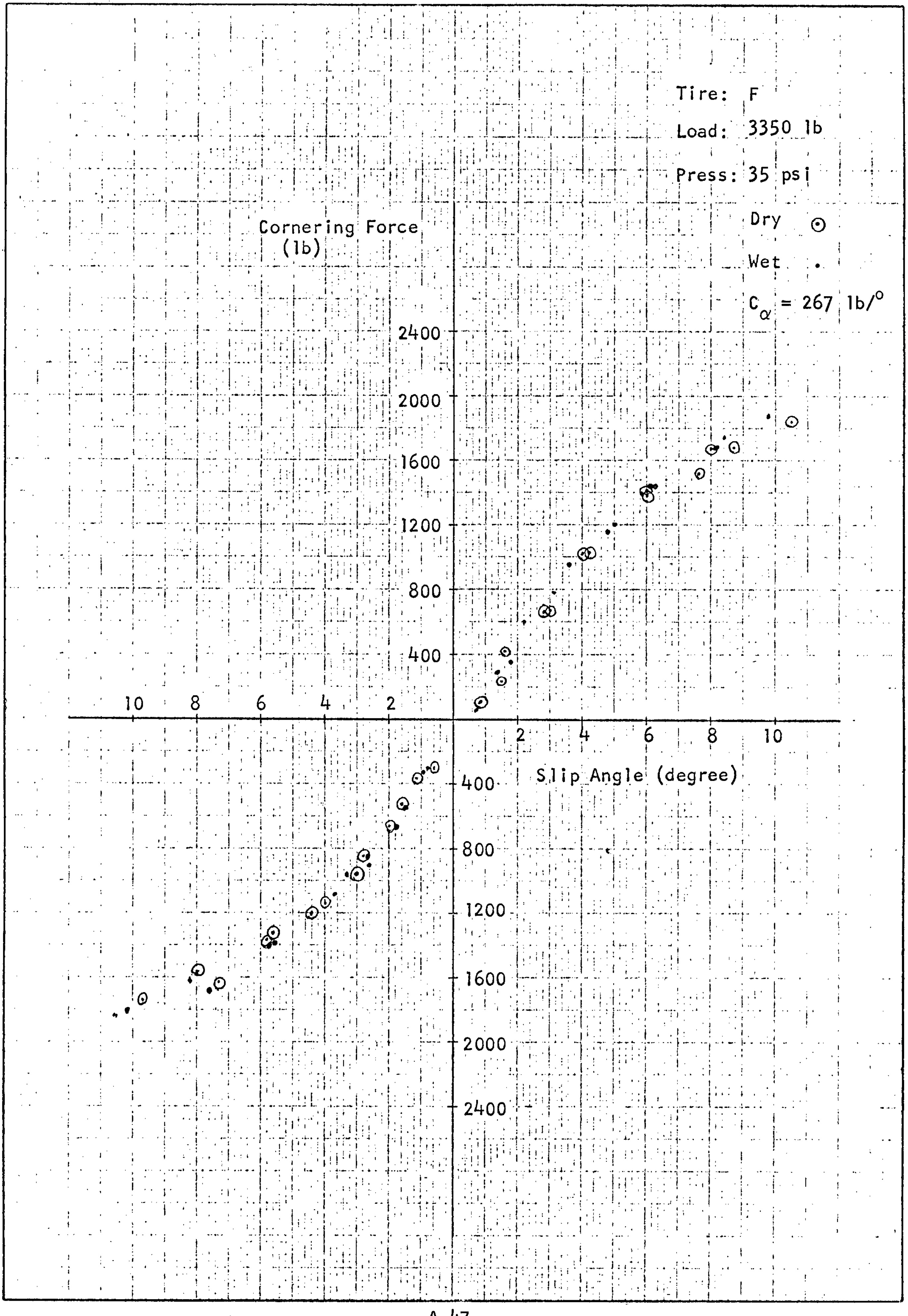

Tire: F
Load: 1504 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400
2

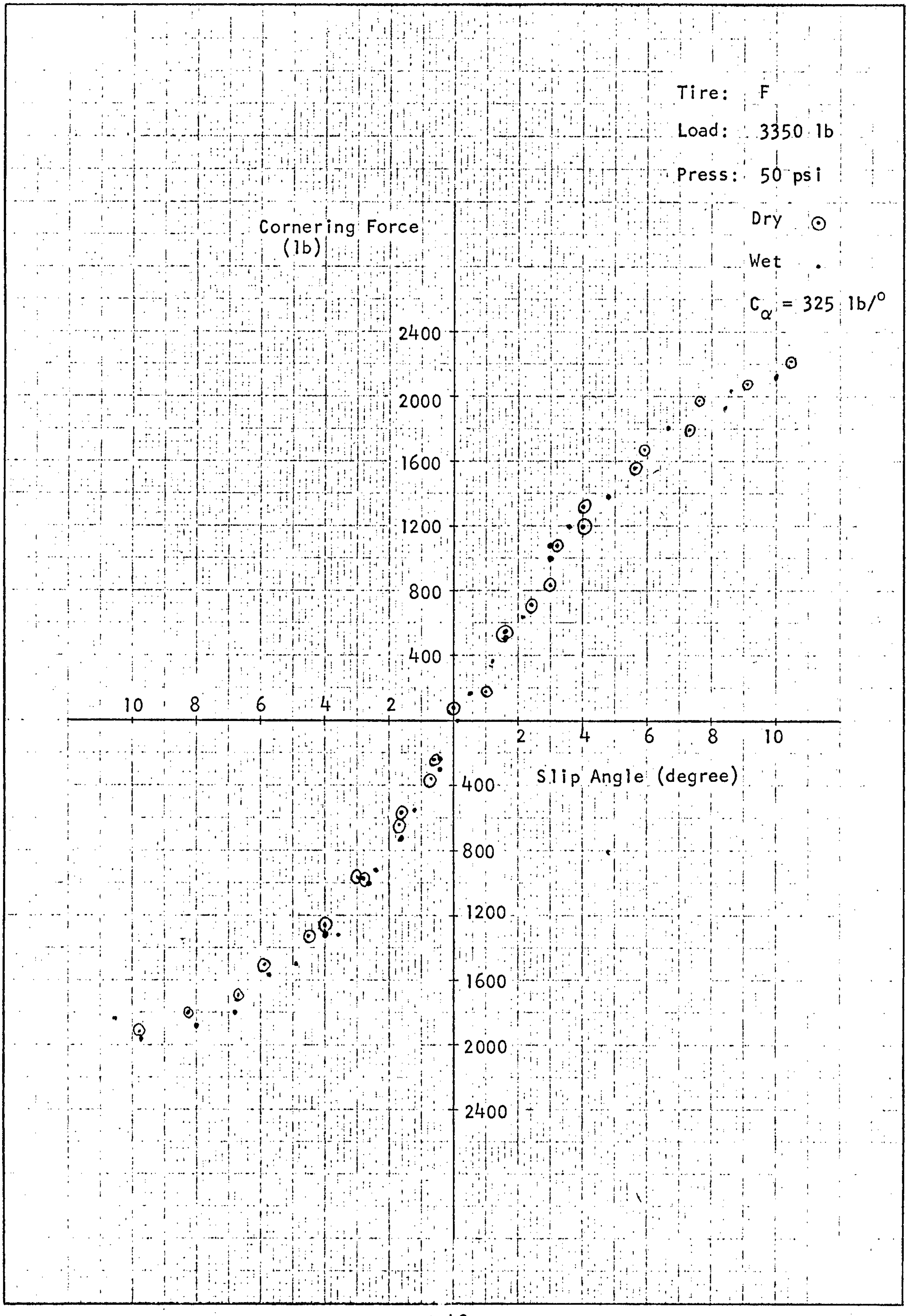

Tire: F
Load: 1504 lb
Press: 50 psi
Dry ⊙
Wet •
C_α = 275 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

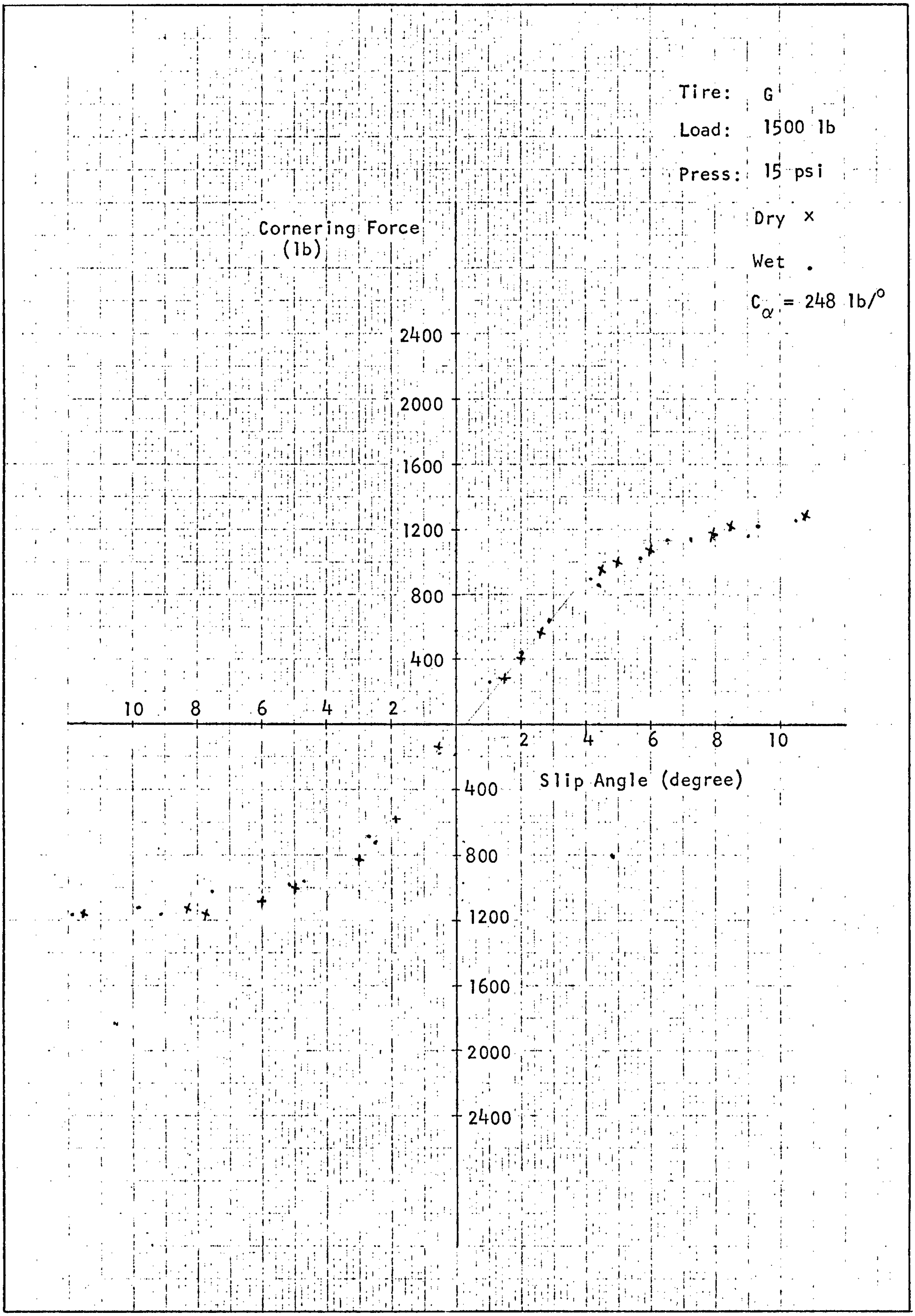

Tire: F
Load: 2168 lb
Press: 15 psi
Dry
Wet
C_α = 192 lb/°
Cornering Force (lb)
Slip Angle (degree)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
400
800
1200
1600
2000
2400

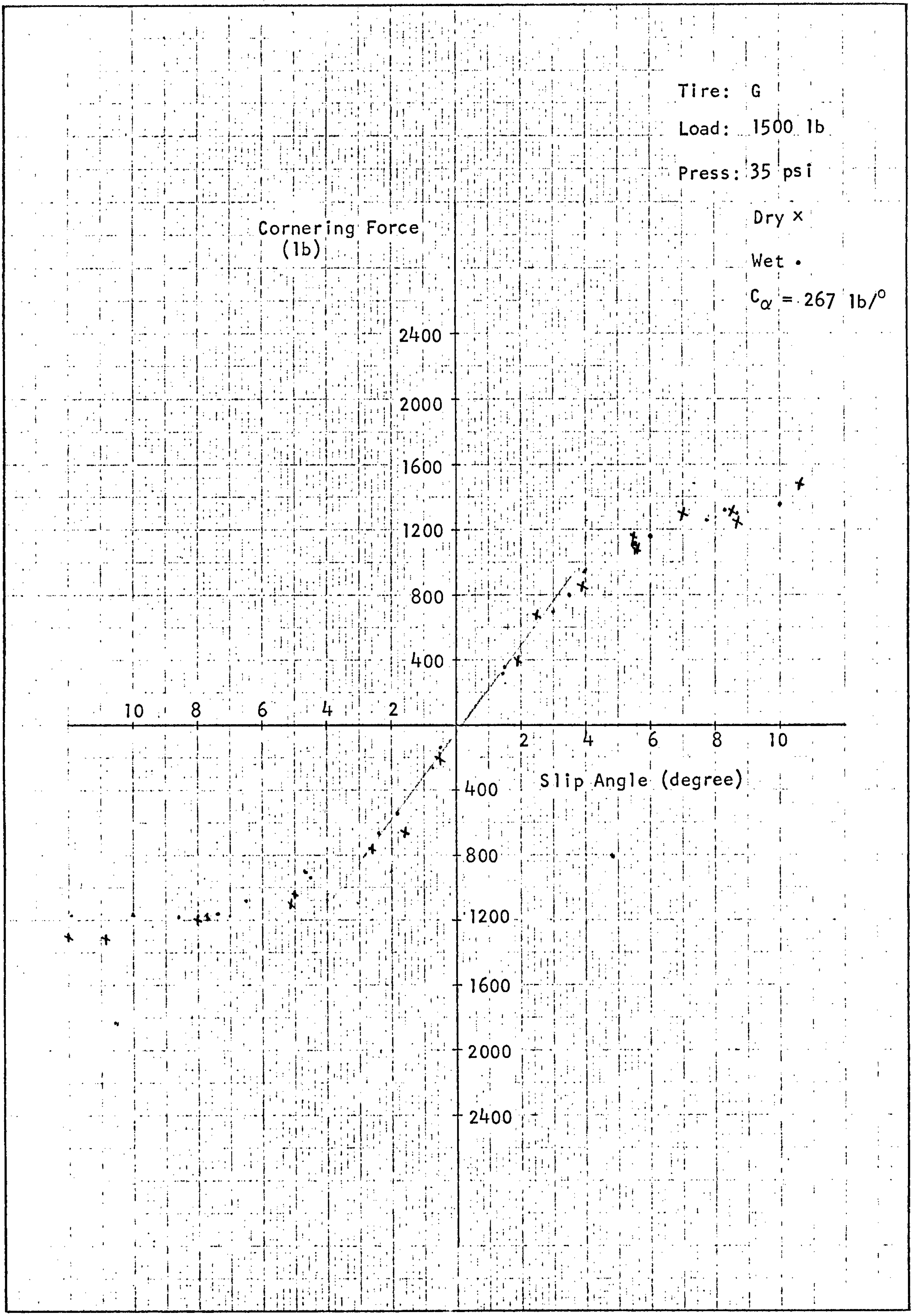

Tire: F
Load: 2168 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: F
Load: 2168 lb
Press: 50 psi
Dry ⊙
Wet •
$C_{\alpha} = 325$ lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

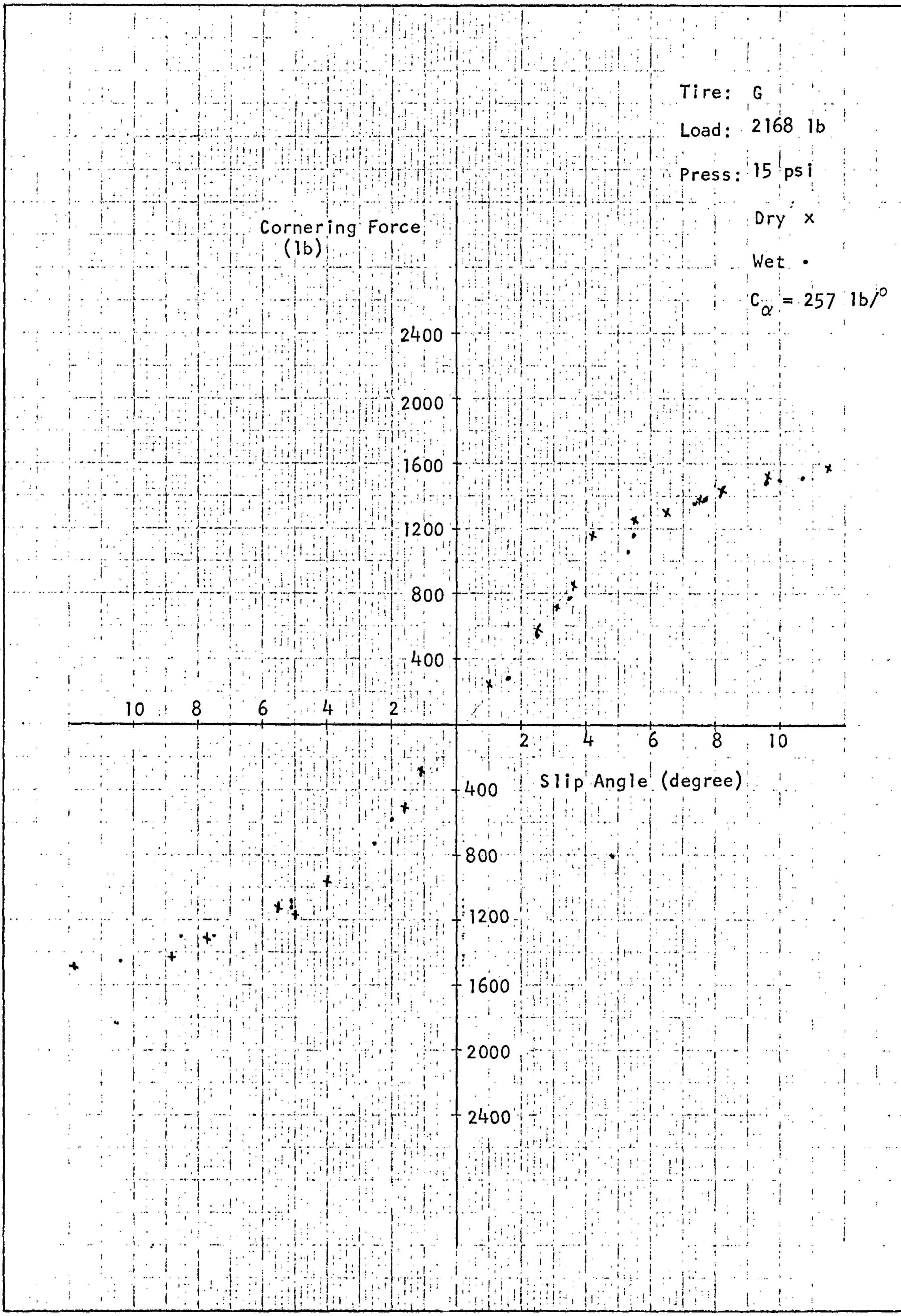

Tire: F
Load: 3350 lb
Press: 35 psi
Dry ⊙
Wet •
C_α = 267 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

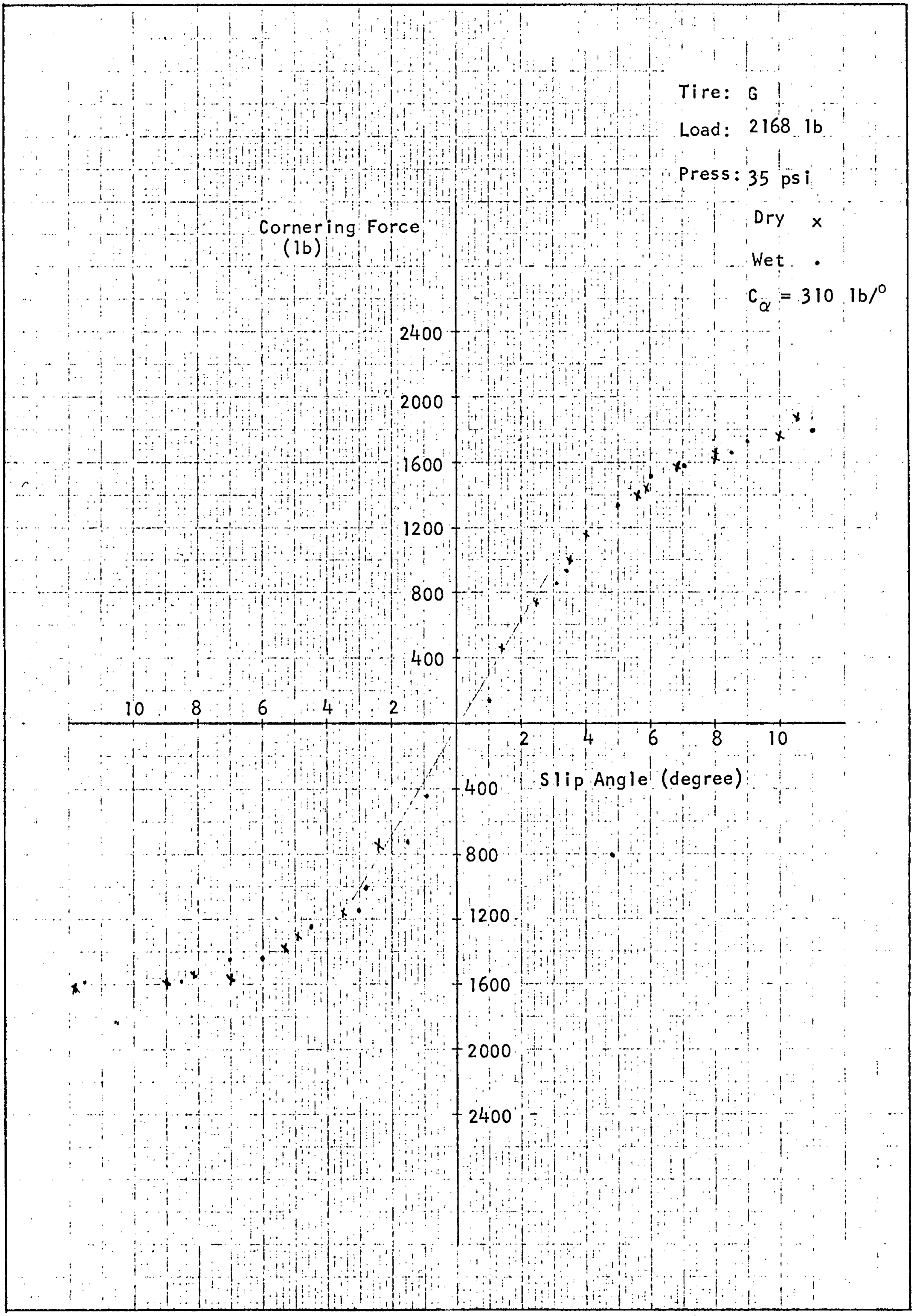

Tire: F
Load: 3350 lb
Press: 50 psi
Dry
Wet
C_α = 325 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

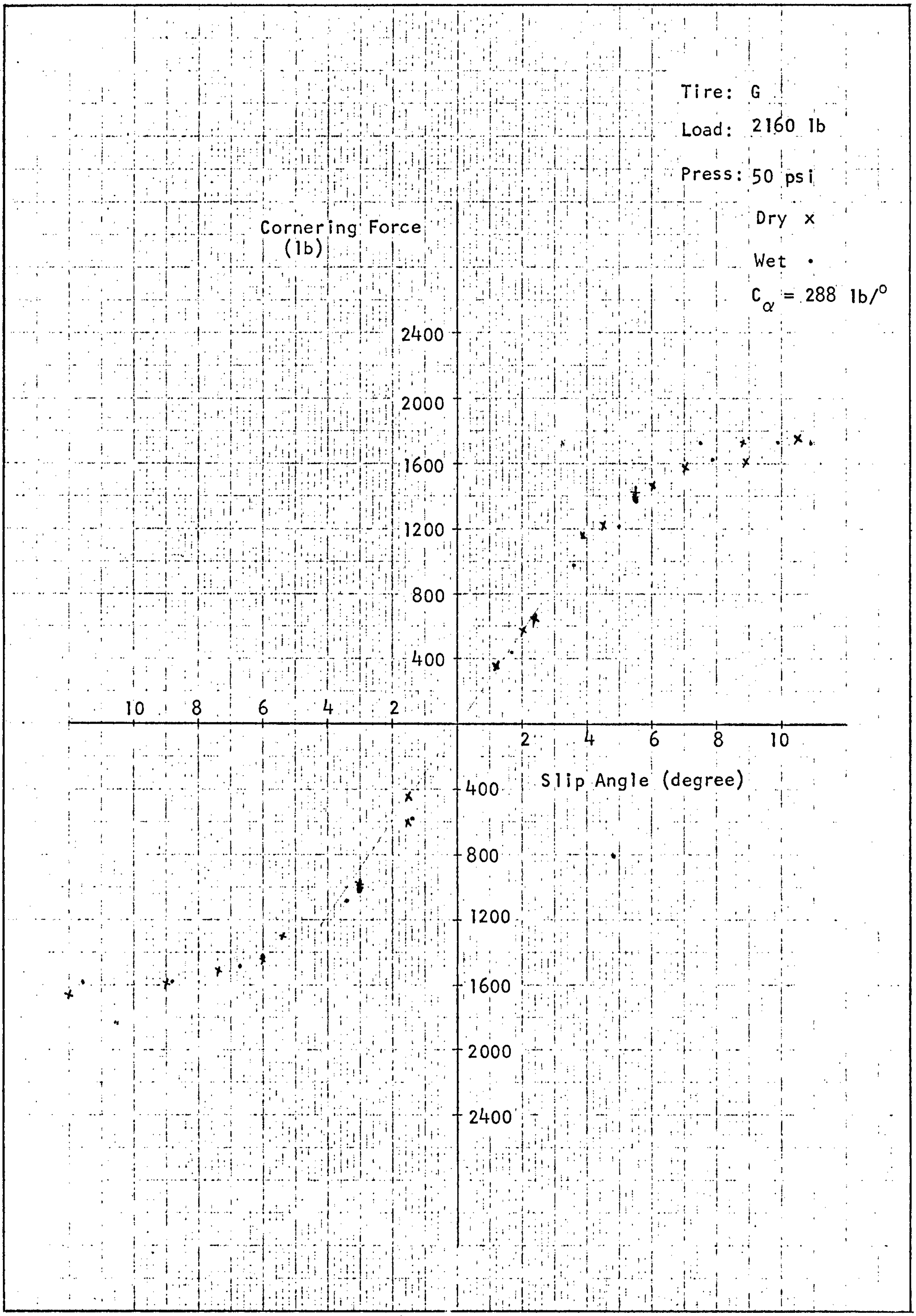

Tire: G
Load: 1500 lb
Press: 15 psi
Dry ×
Wet .
Cα = 248 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

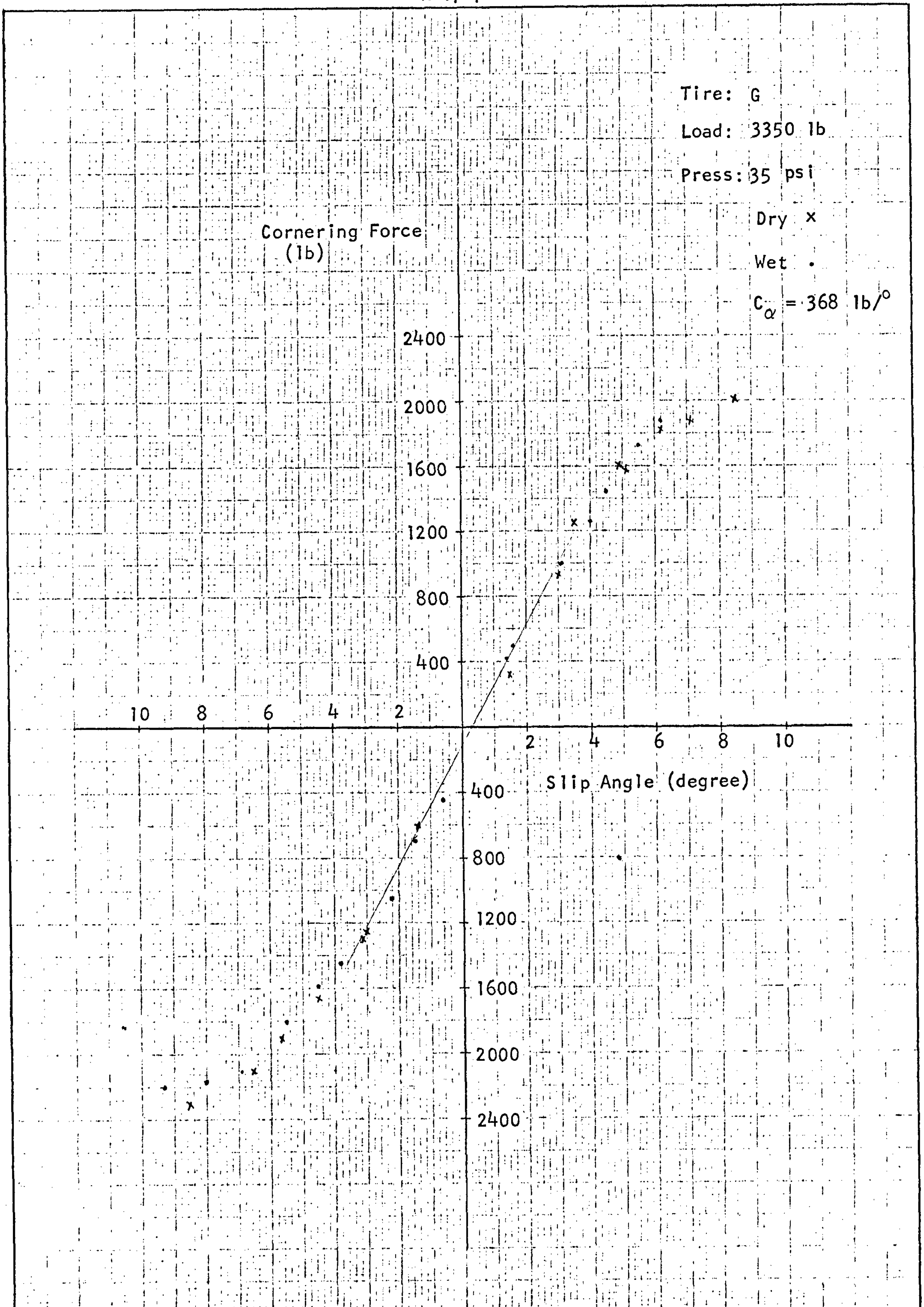


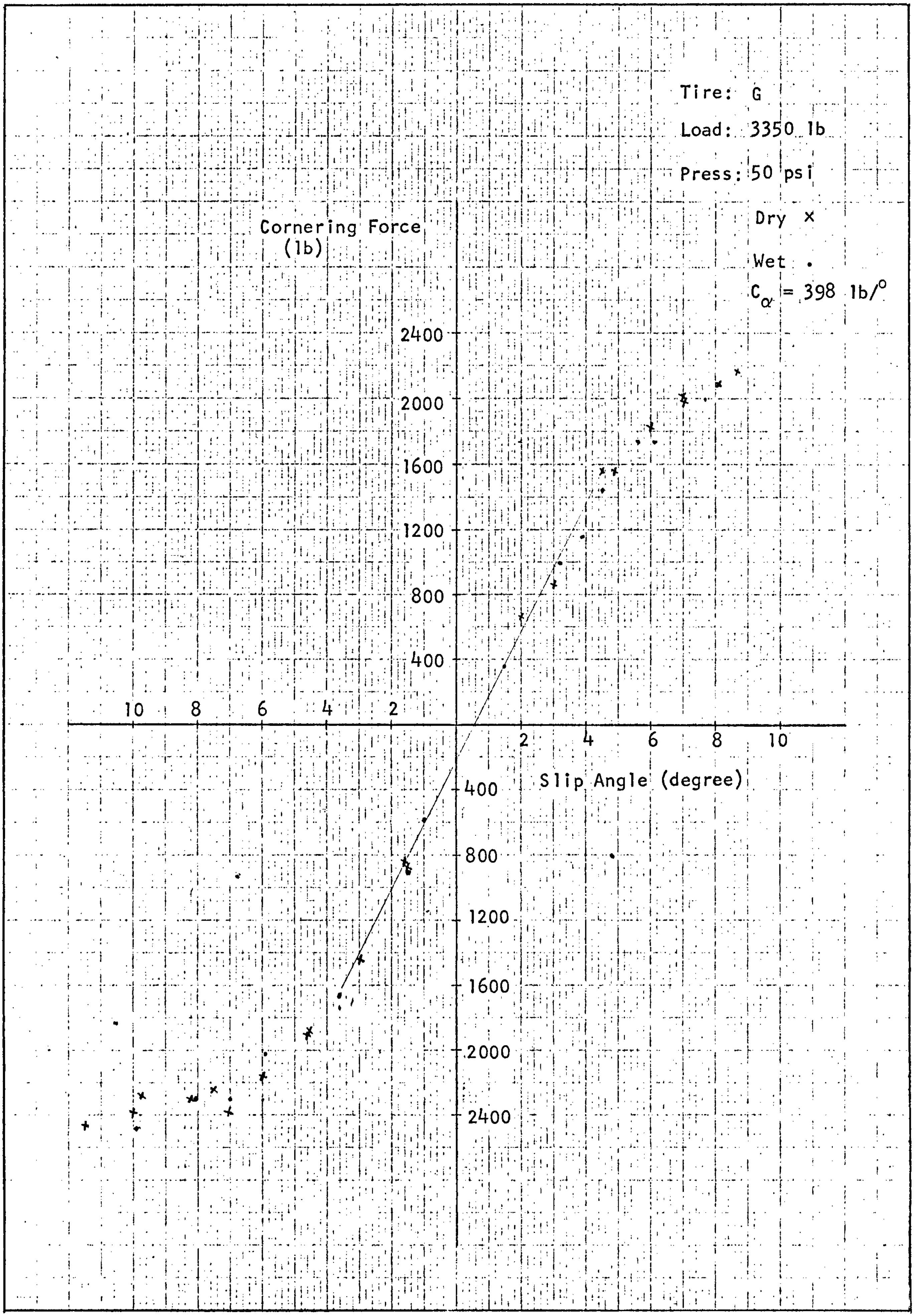
Tire: G
Load: 1500 lb
Press: 35 psi
Dry ×
Wet •
C_α = 267 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

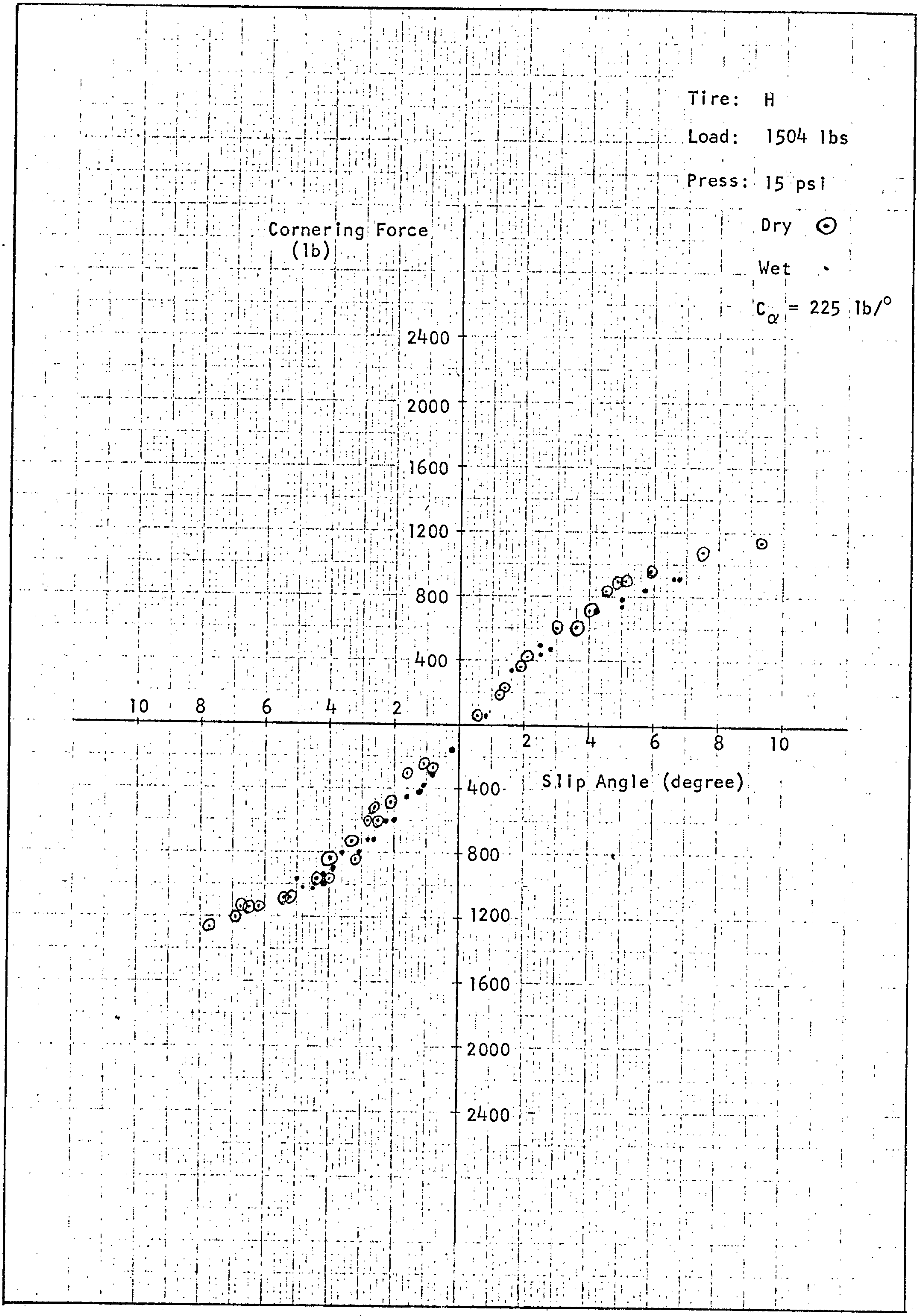

Tire: G
Load: 2168 lb
Press: 15 psi
Dry x
Wet •
C_α = 257 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

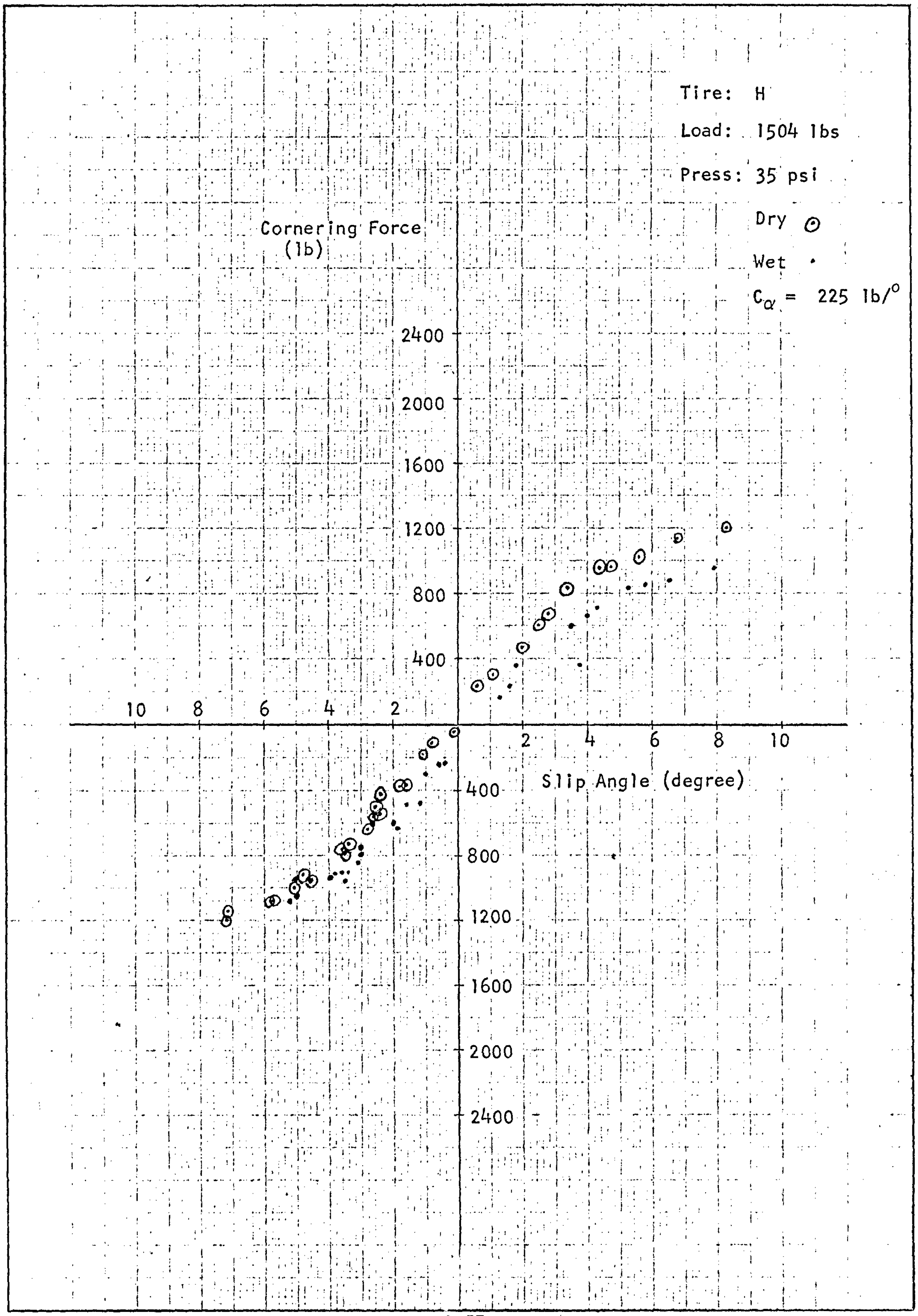

Tire: G
Load: 2168 lb
Press: 35 psi
Dry x
Wet •
C_α = 310 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

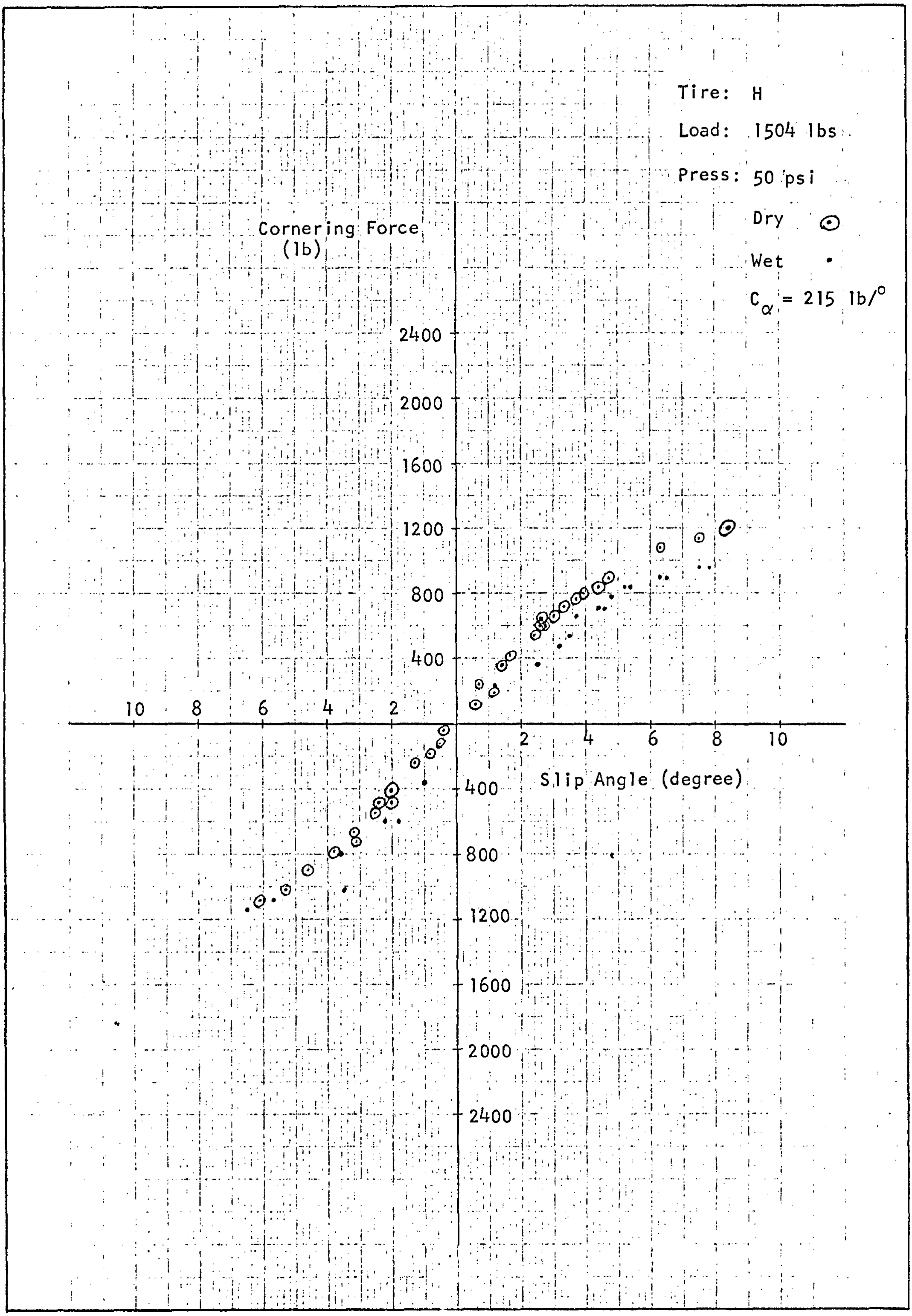

Tire: G
Load: 2160 lb
Press: 50 psi
Dry x
Wet •
C_α = 288 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: G
Load: 3350 lb
Press: 35 psi
Dry ×
Wet •
C_α = 368 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

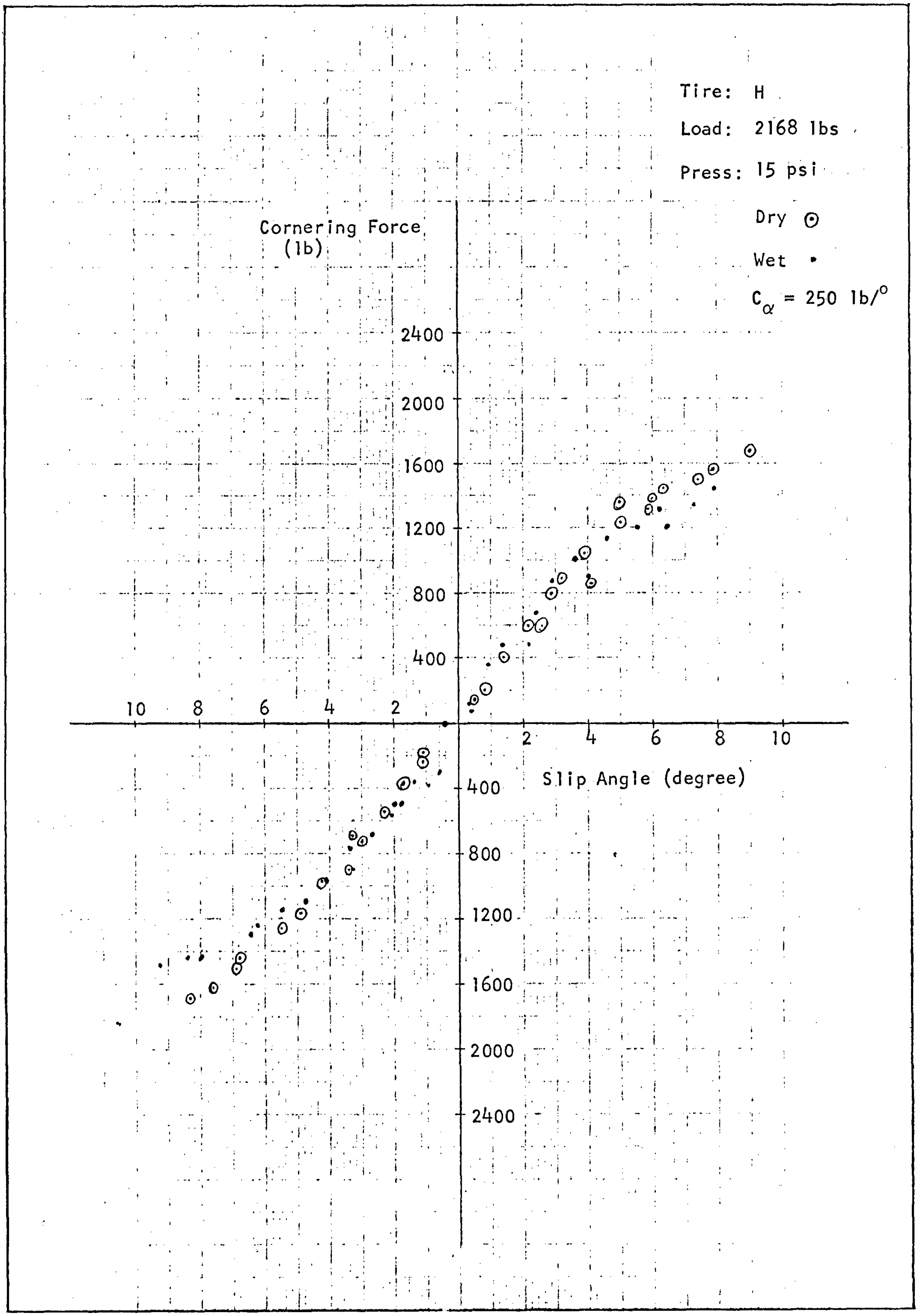

Tire: G
Load: 3350 lb
Press: 50 psi
Dry ×
Wet •
C_α = 398 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

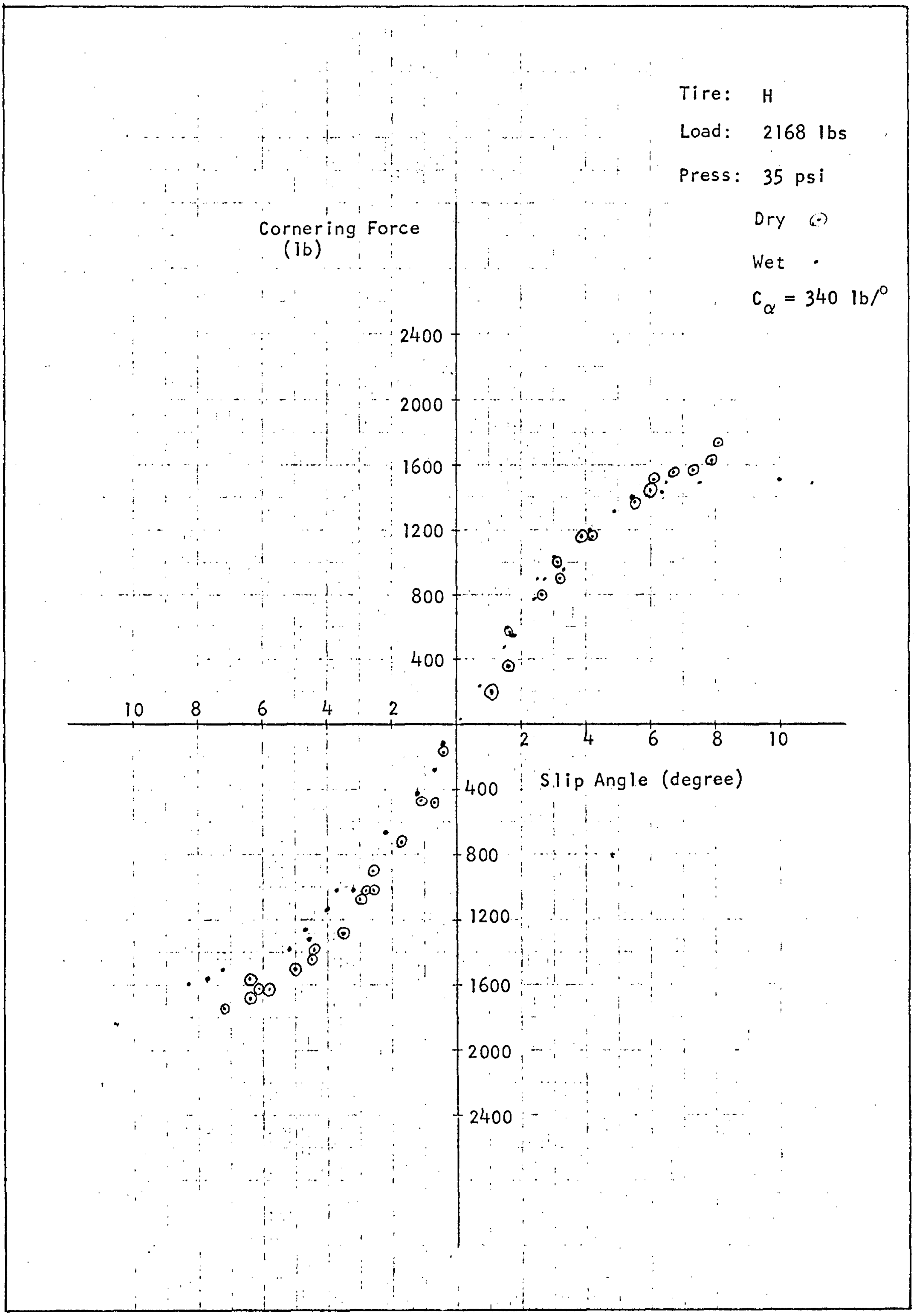

Tire: H
Load: 1504 lbs
Press: 15 psi
Dry ⊙
Wet •
C_α = 225 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

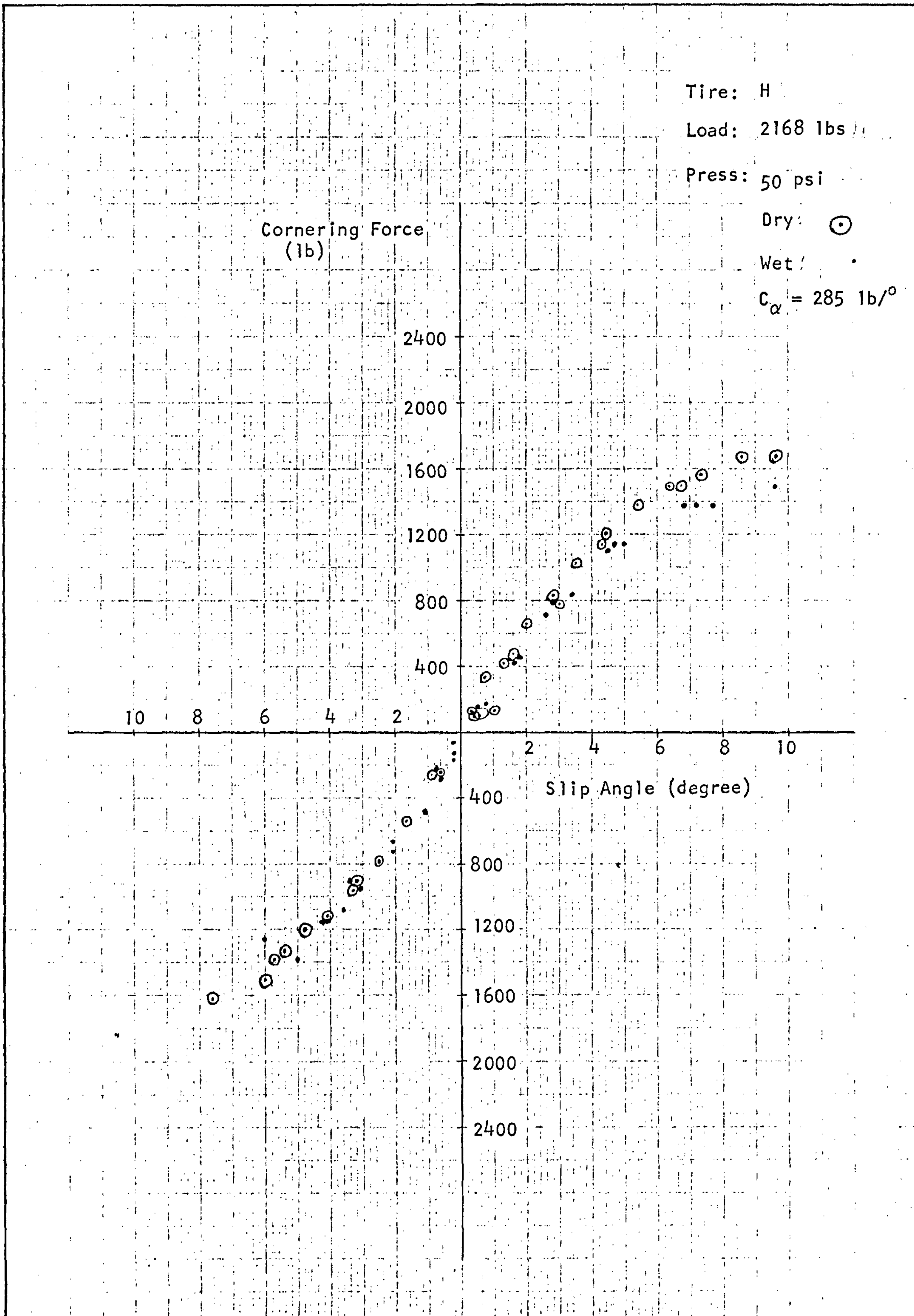

Tire: H
Load: 1504 lbs
Press: 35 psi
Dry
Wet
C_α = 225 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

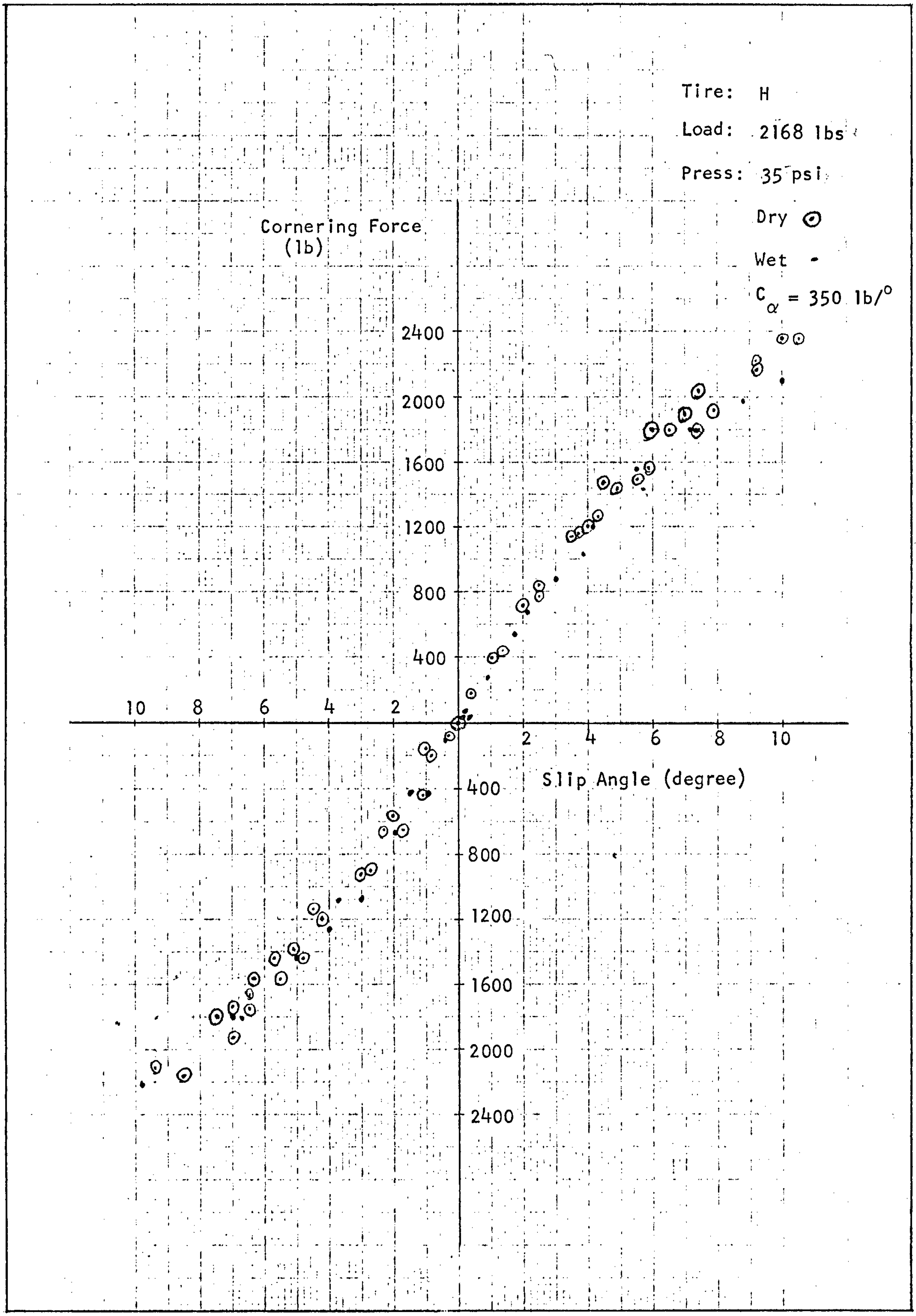


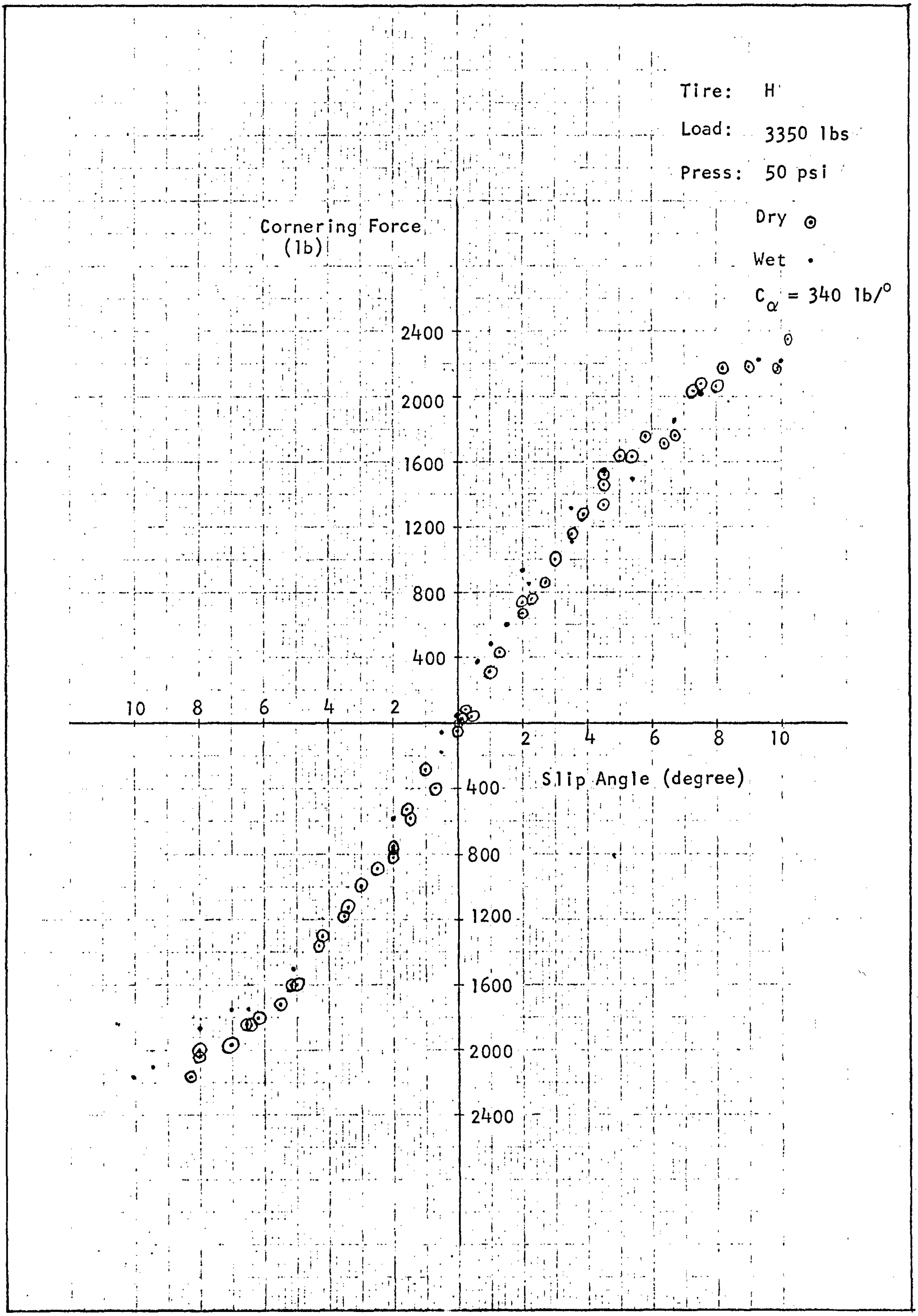
Tire: H
Load: 1504 lbs
Press: 50 psi
Dry
Wet
C_α = 215 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

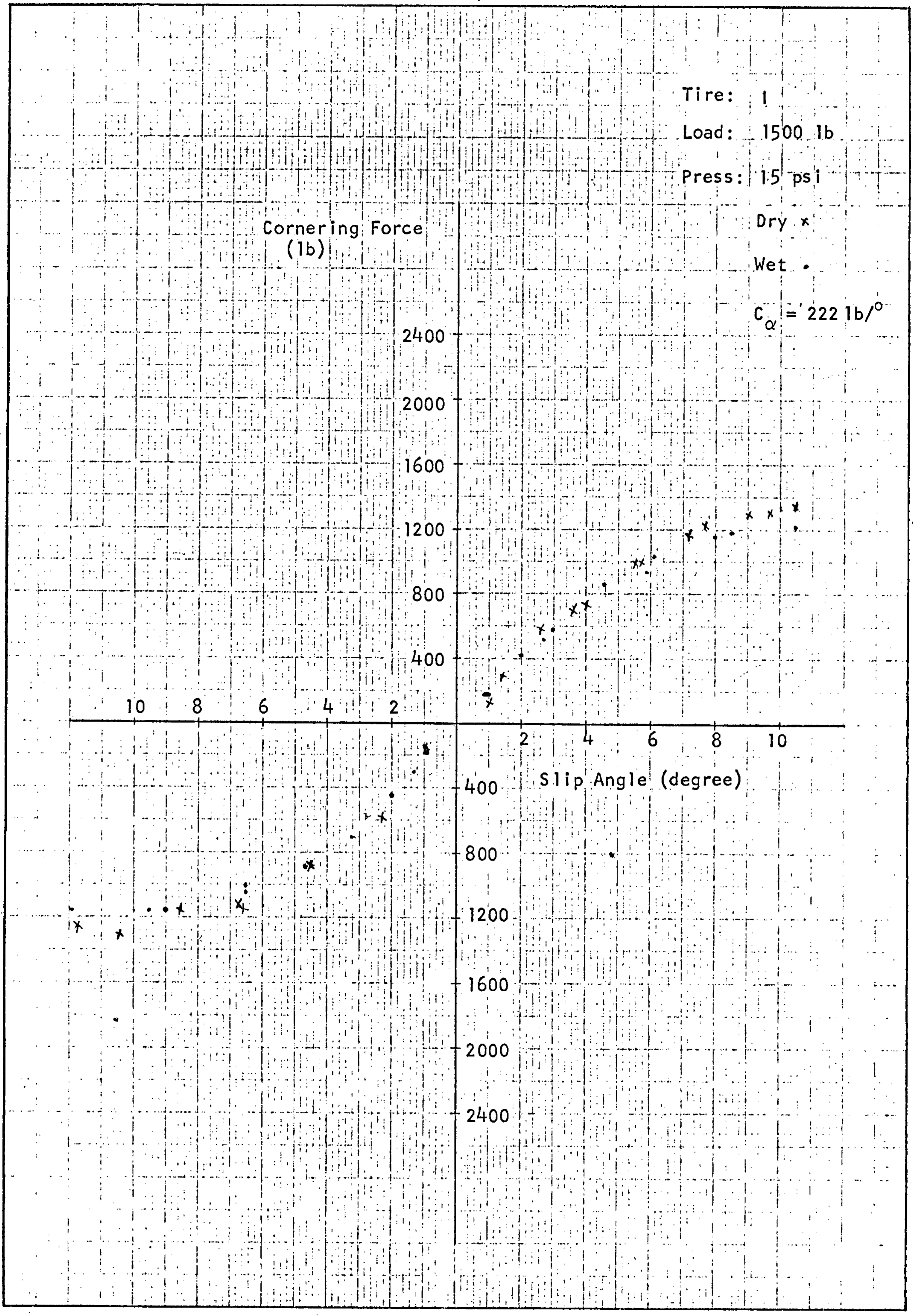

Tire: H
Load: 2168 lbs
Press: 15 psi
Dry
Wet
C_α = 250 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

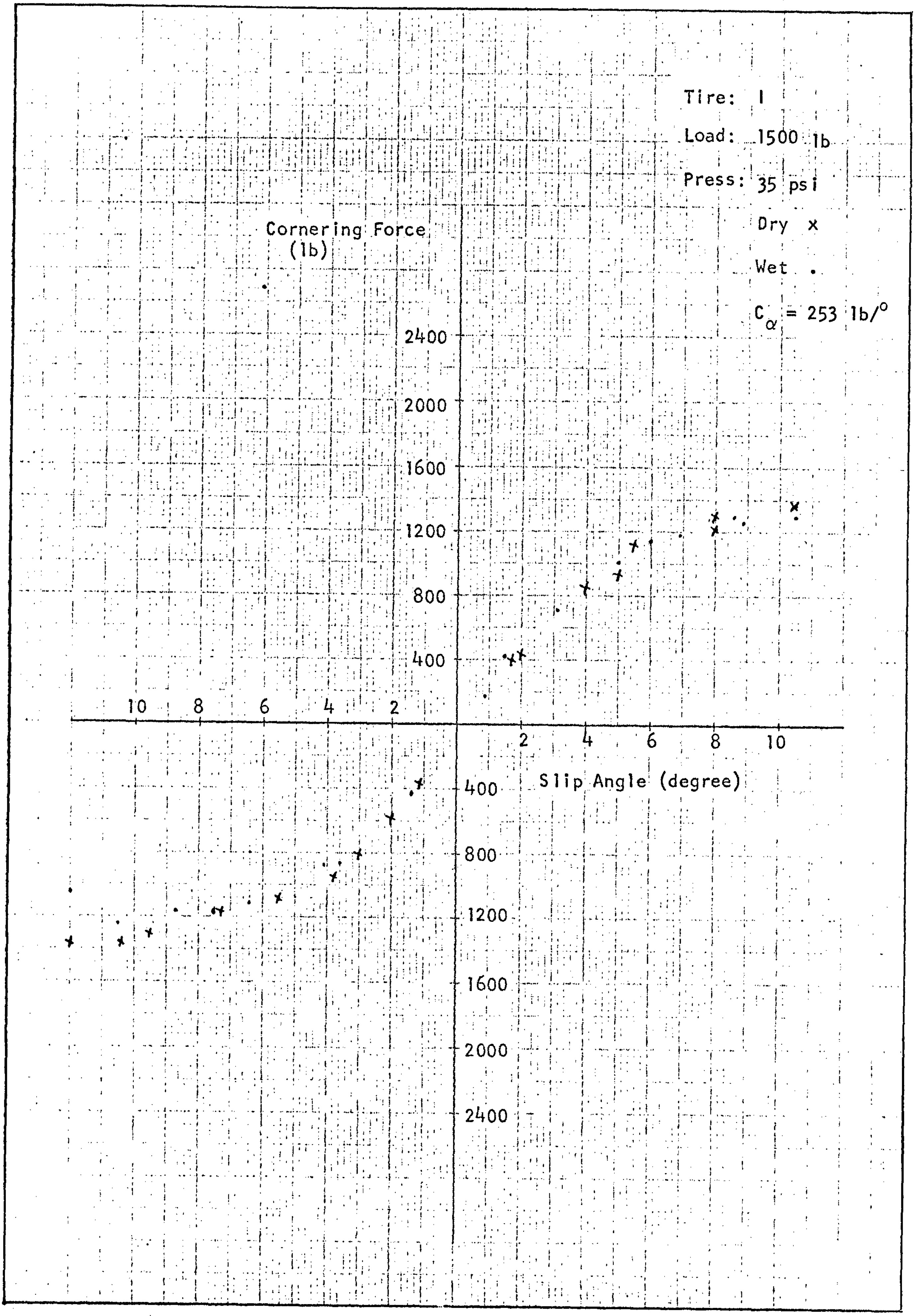

Tire: H
Load: 2168 lbs
Press: 35 psi
Dry
Wet
C_α = 340 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

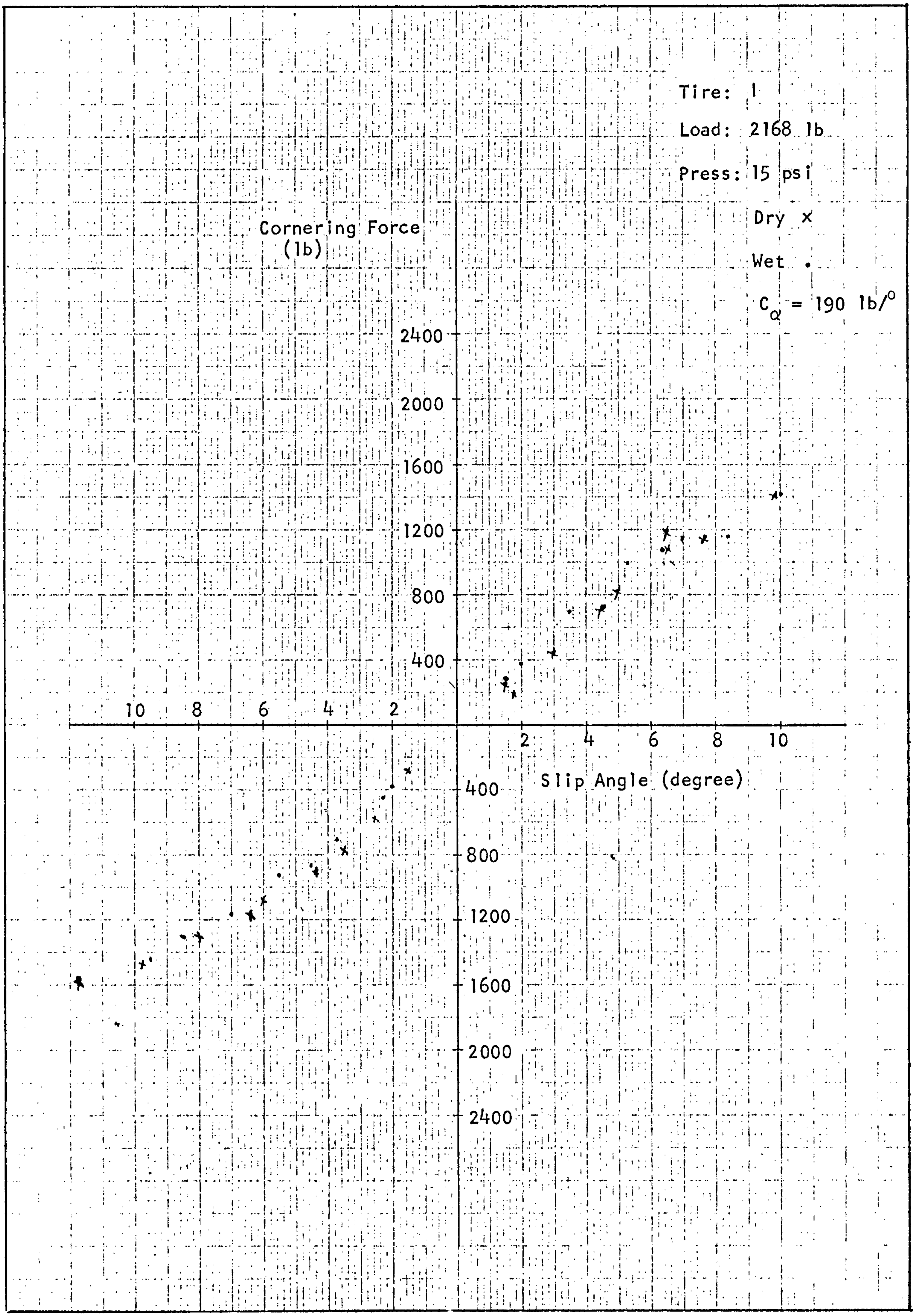

Tire: H
Load: 2168 lbs
Press: 50 psi
Dry: ⊙
Wet: •
C_α = 285 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

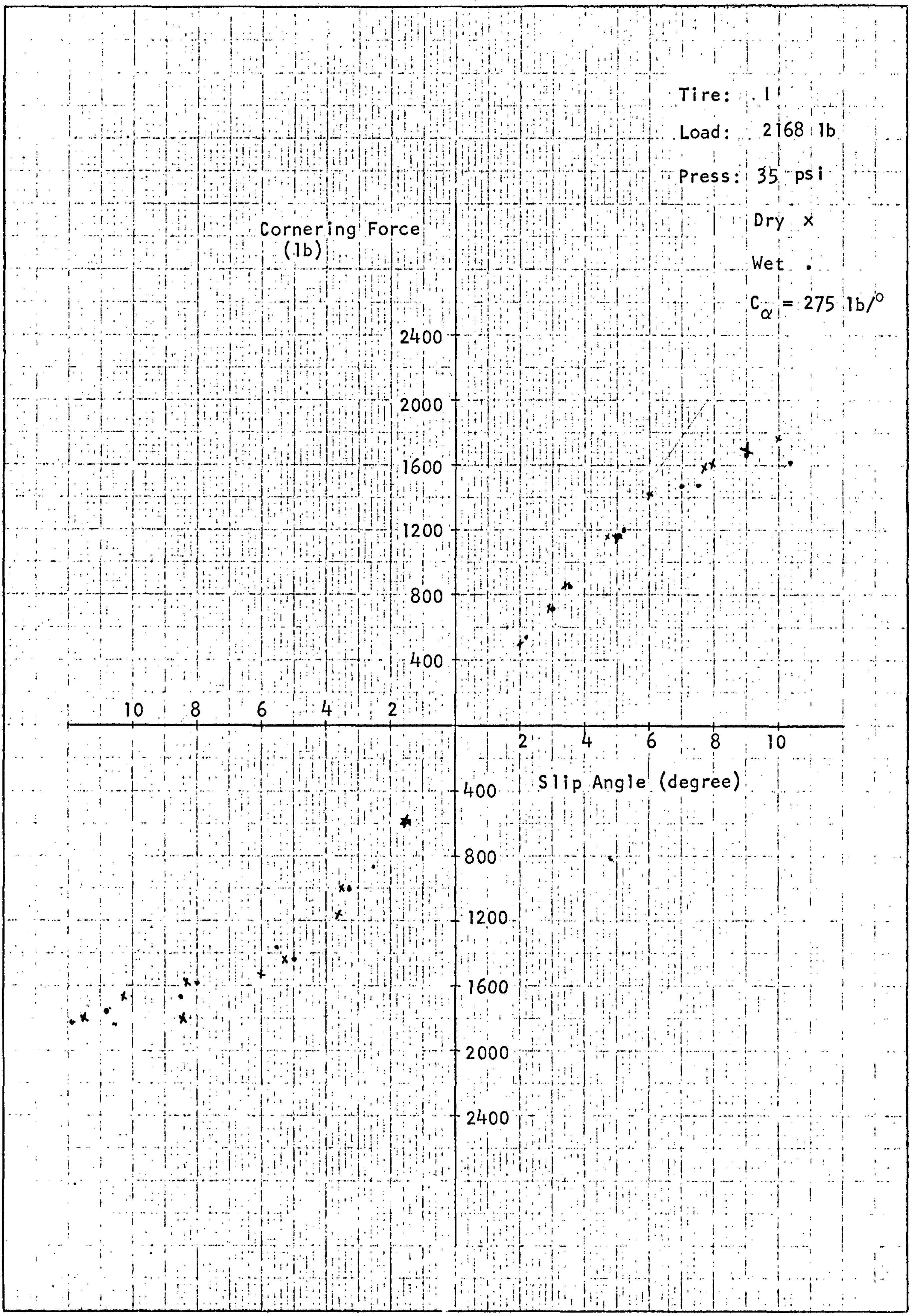

Tire: H
Load: 2168 lbs
Press: 35 psi
Dry
Wet
C_{α} = 350 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

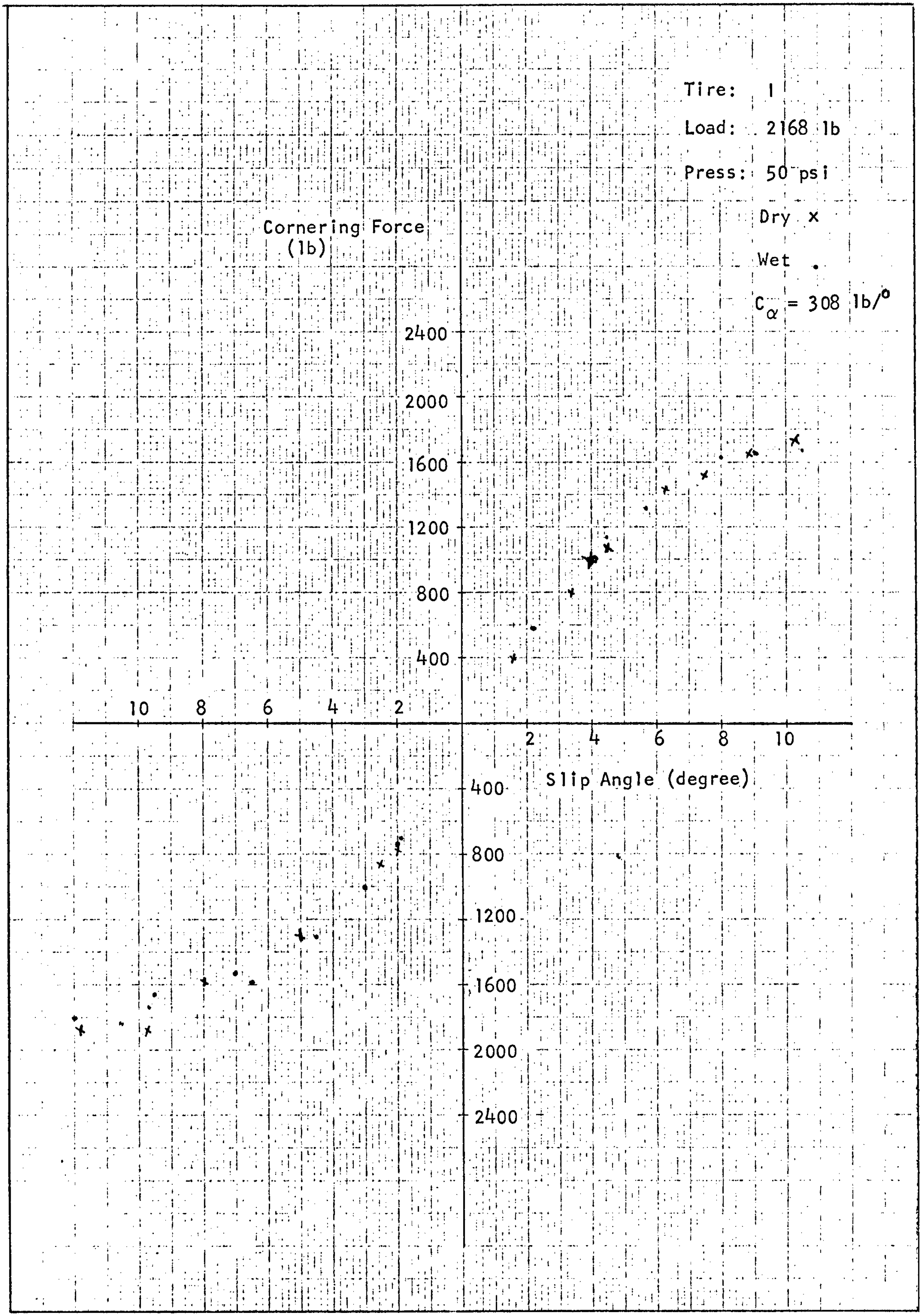

Tire: H
Load: 3350 lbs
Press: 50 psi
Dry ⊙
Wet •
C_α = 340 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
Slip Angle (degree)

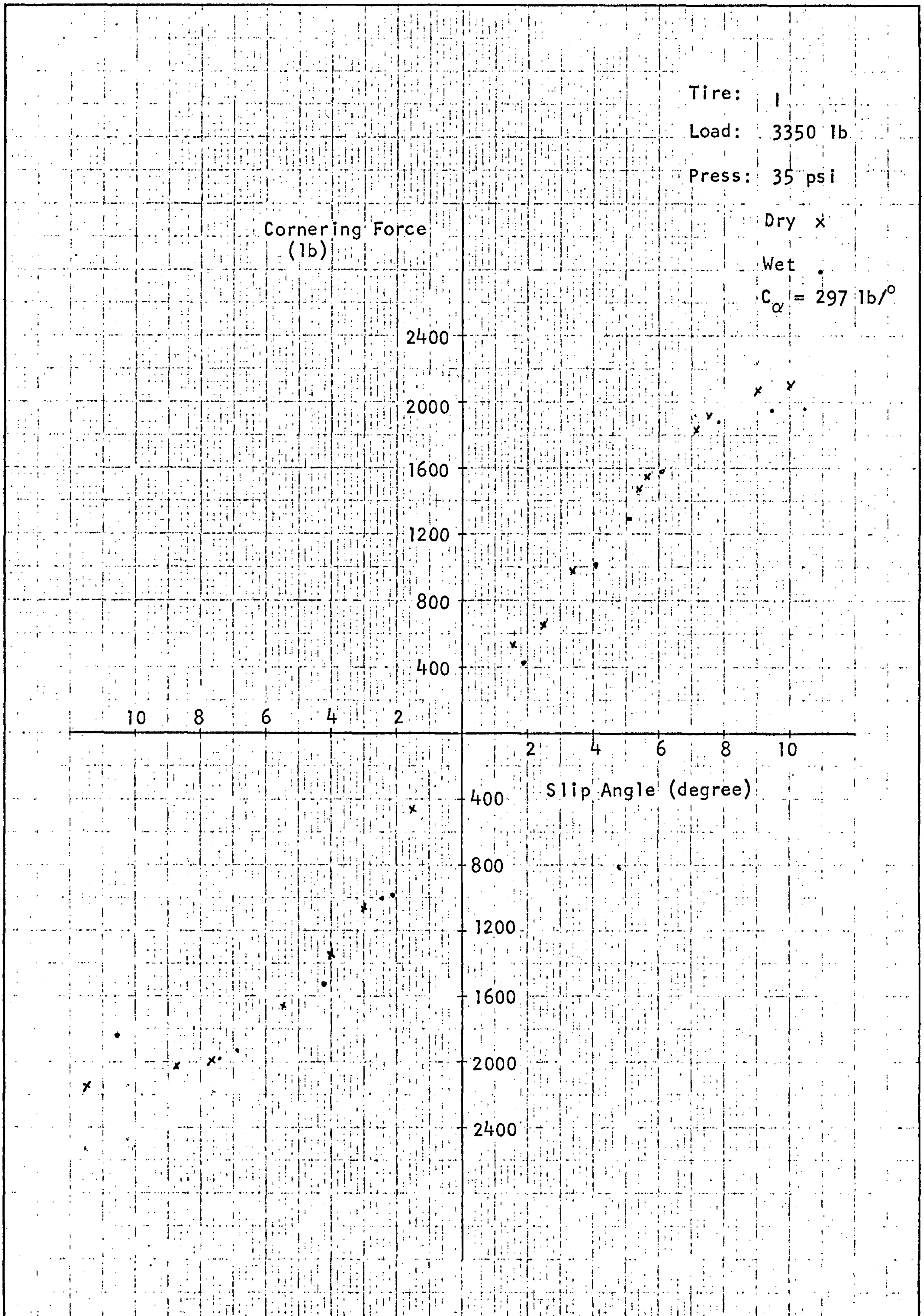

Tire: 1
Load: 1500 lb
Press: 15 psi
Dry ×
Wet •
C_α = 222 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: I
Load: 1500 lb
Press: 35 psi
Dry x
Wet .
Cα = 253 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

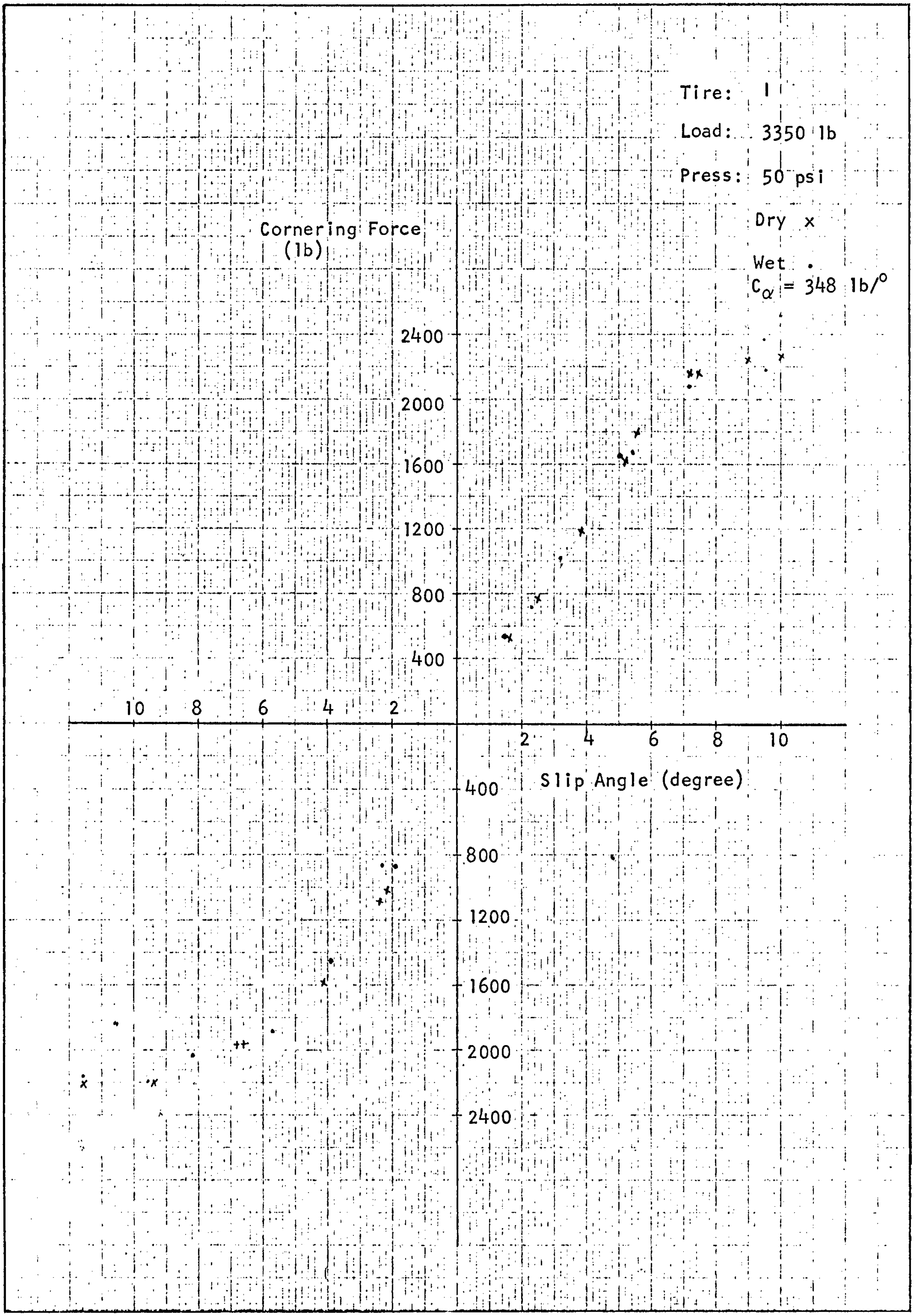

Tire: 1
Load: 2168 lb
Press: 15 psi
Dry ×
Wet •
C_α = 190 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: 1
Load: 2168 lb
Press: 35 psi
Dry x
Wet .
C_α = 275 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

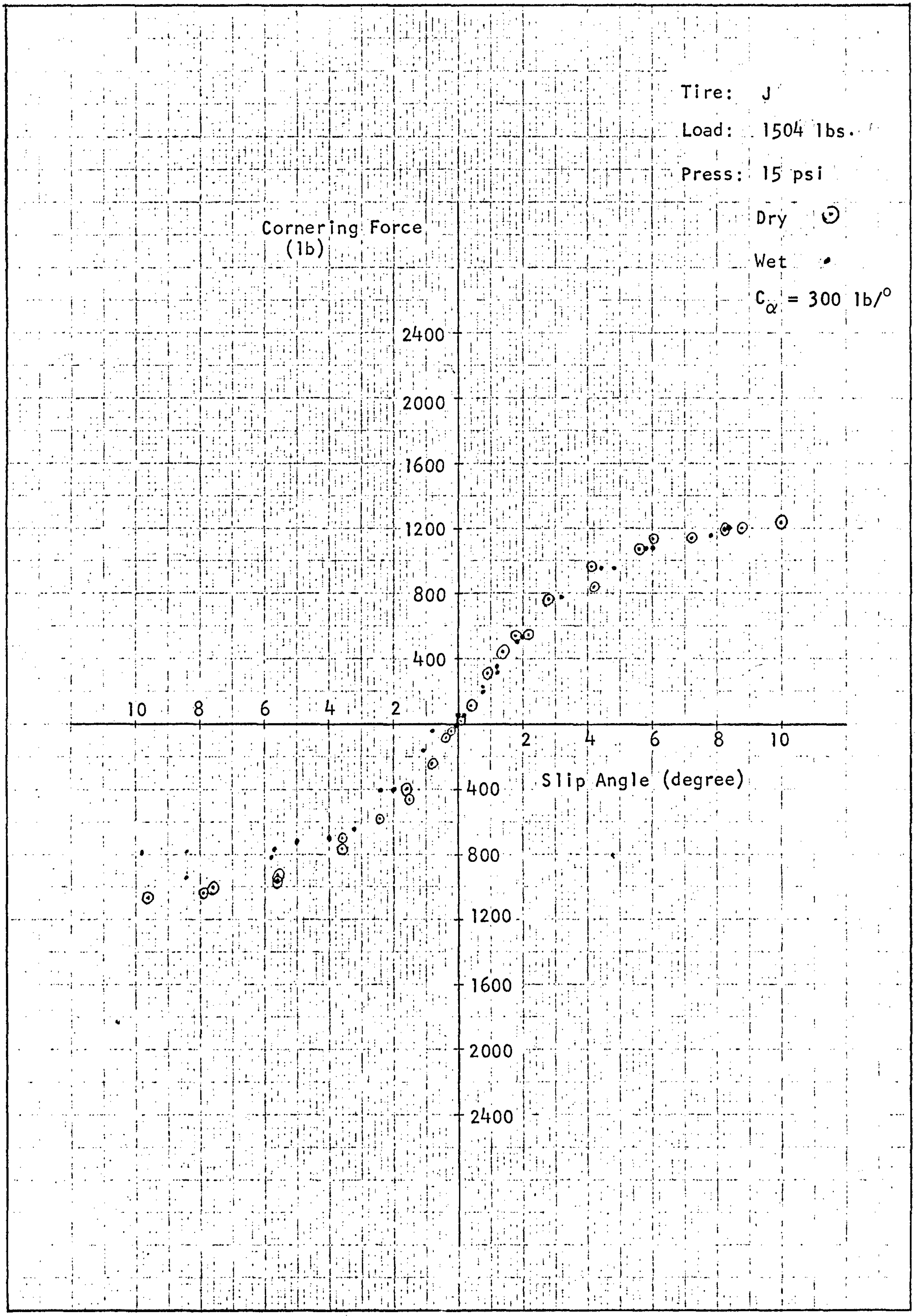

Tire: 1
Load: 2168 lb
Press: 50 psi
Dry ×
Wet •
C_α = 308 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

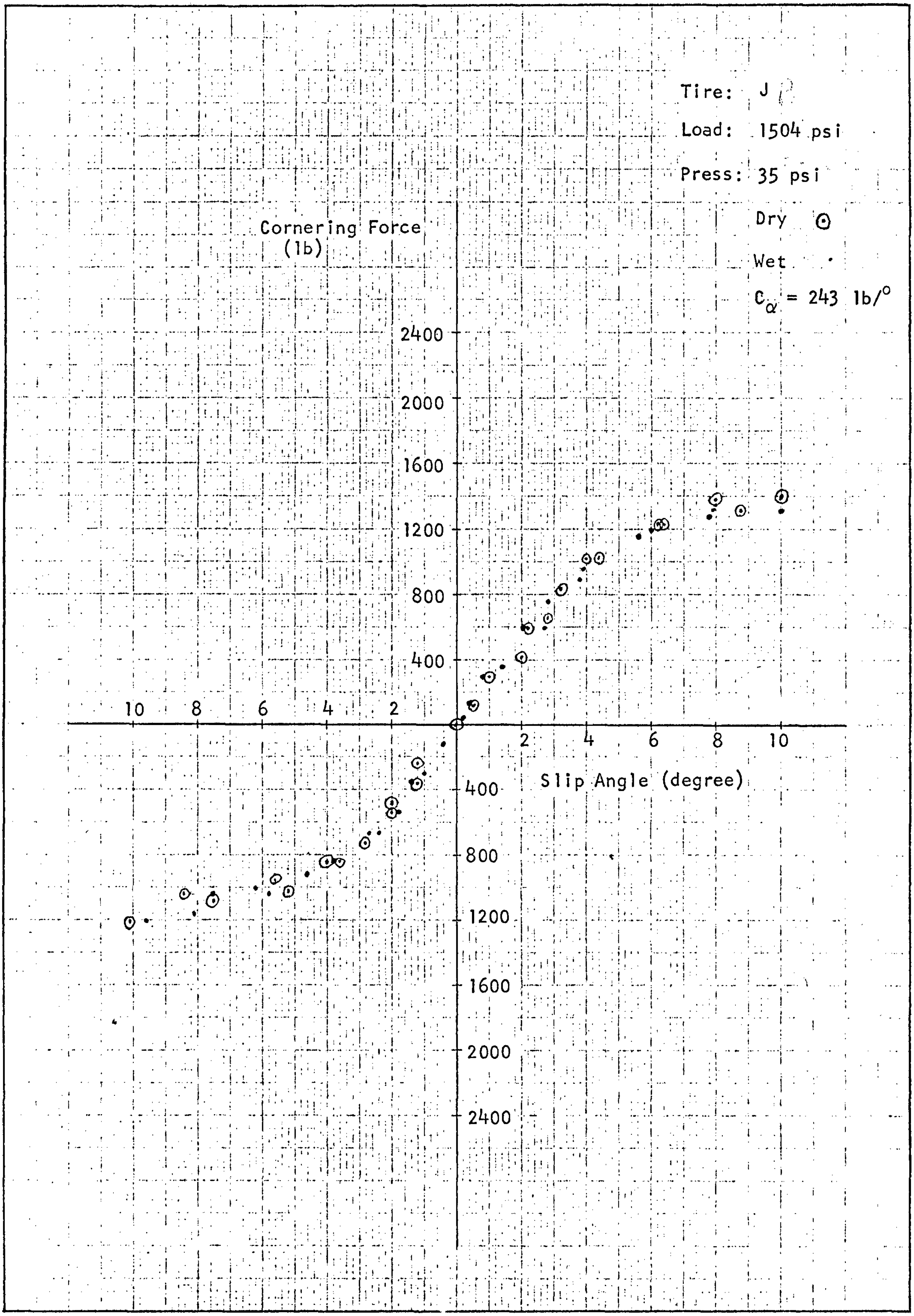


Tire: I
Load: 3350 lb
Press: 35 psi
Dry x
Wet •
C_α = 297 lb/°
Cornering Force
(lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

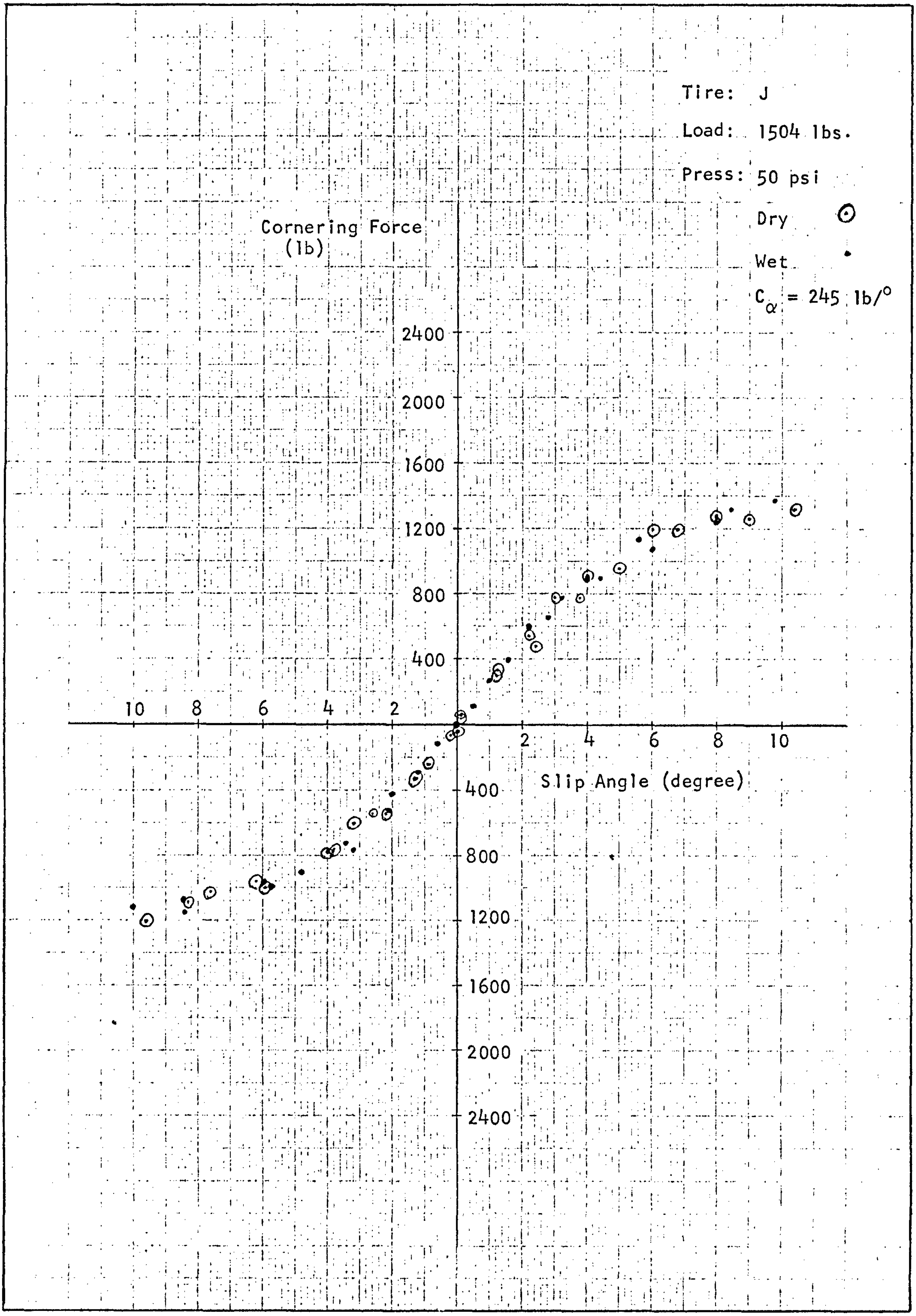


Tire: I
Load: 3350 lb
Press: 50 psi
Dry x
Wet •
C_α = 348 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

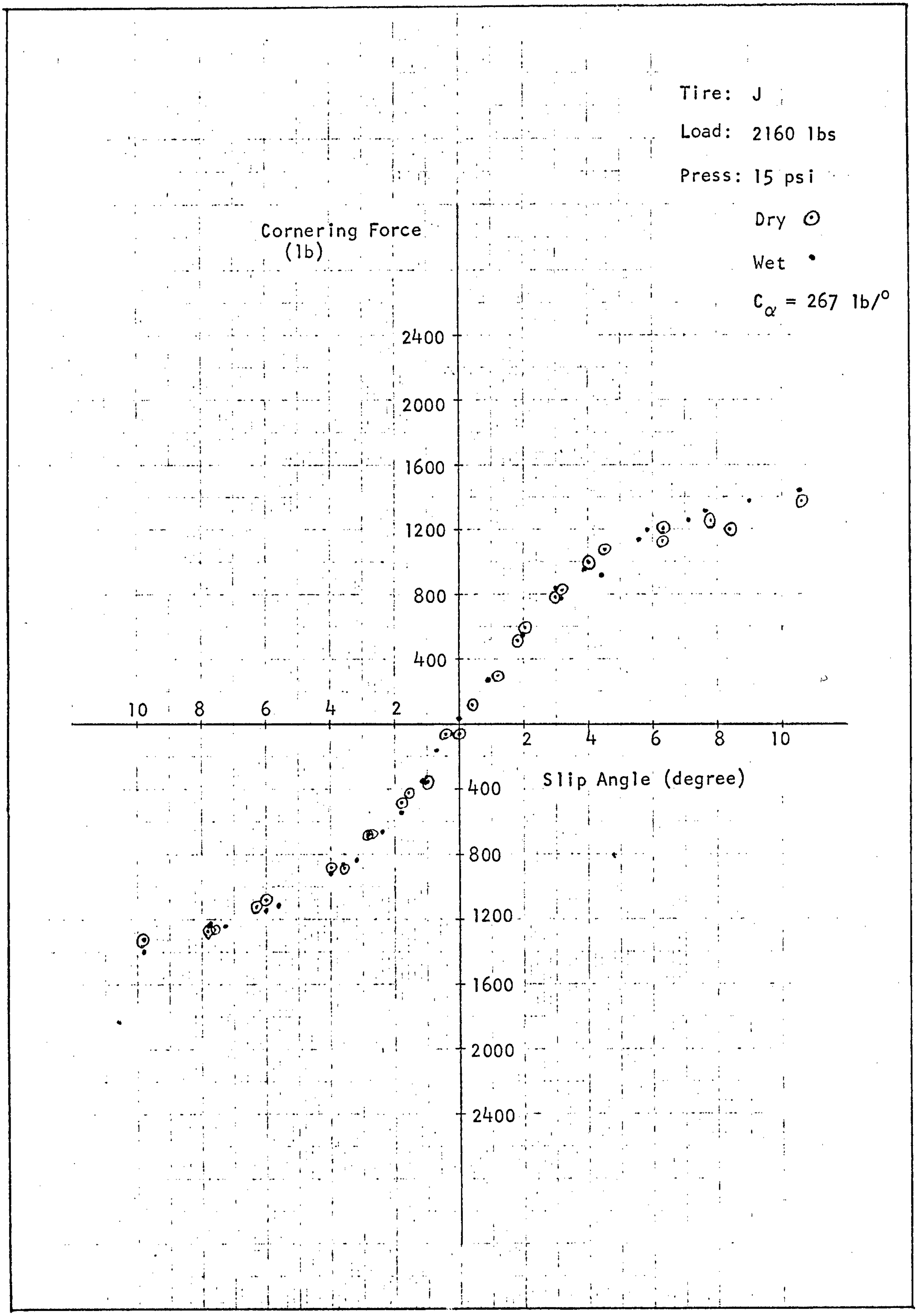

Tire: J
Load: 1504 lbs.
Press: 15 psi
Dry
Wet
C_α = 300 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

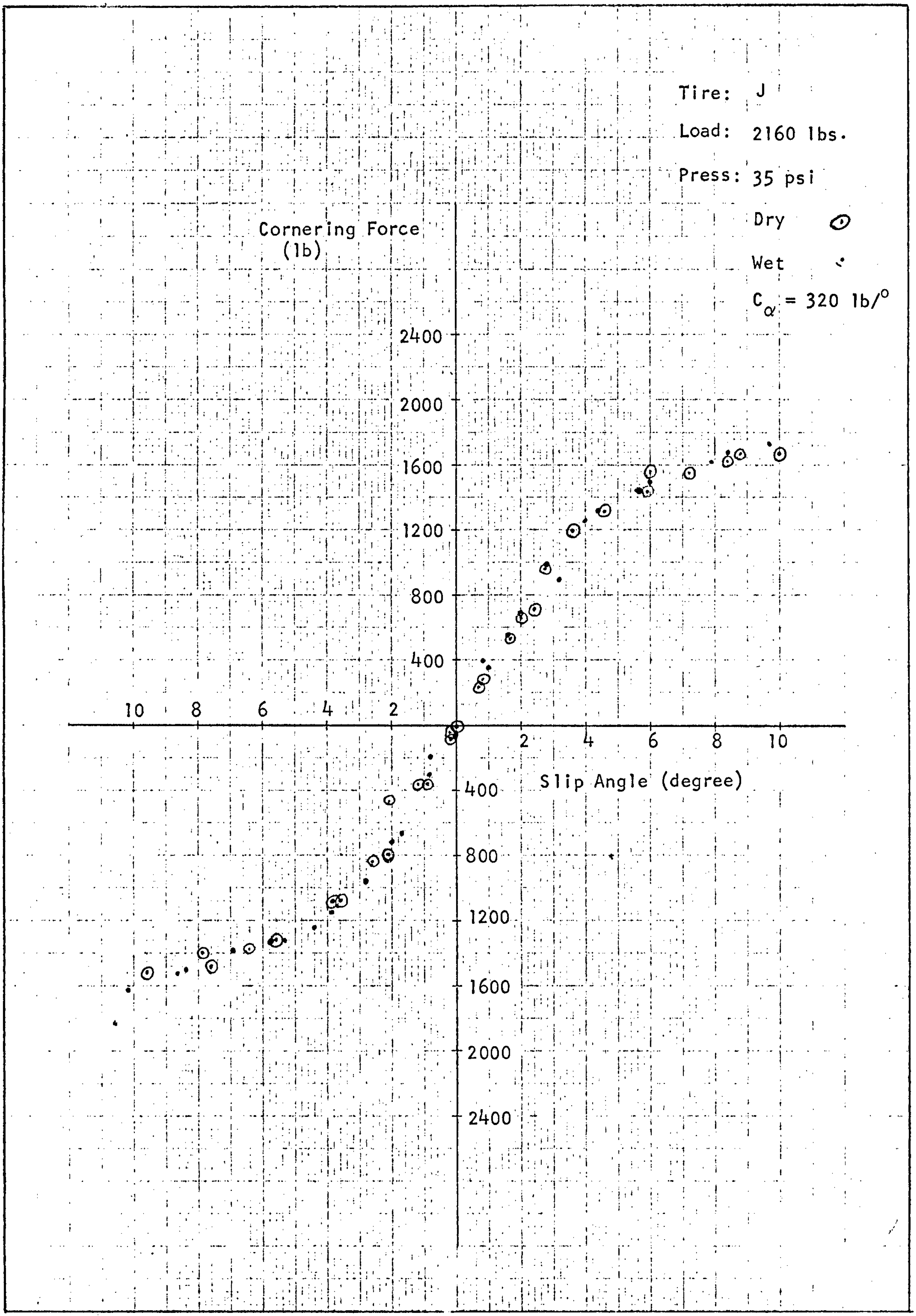


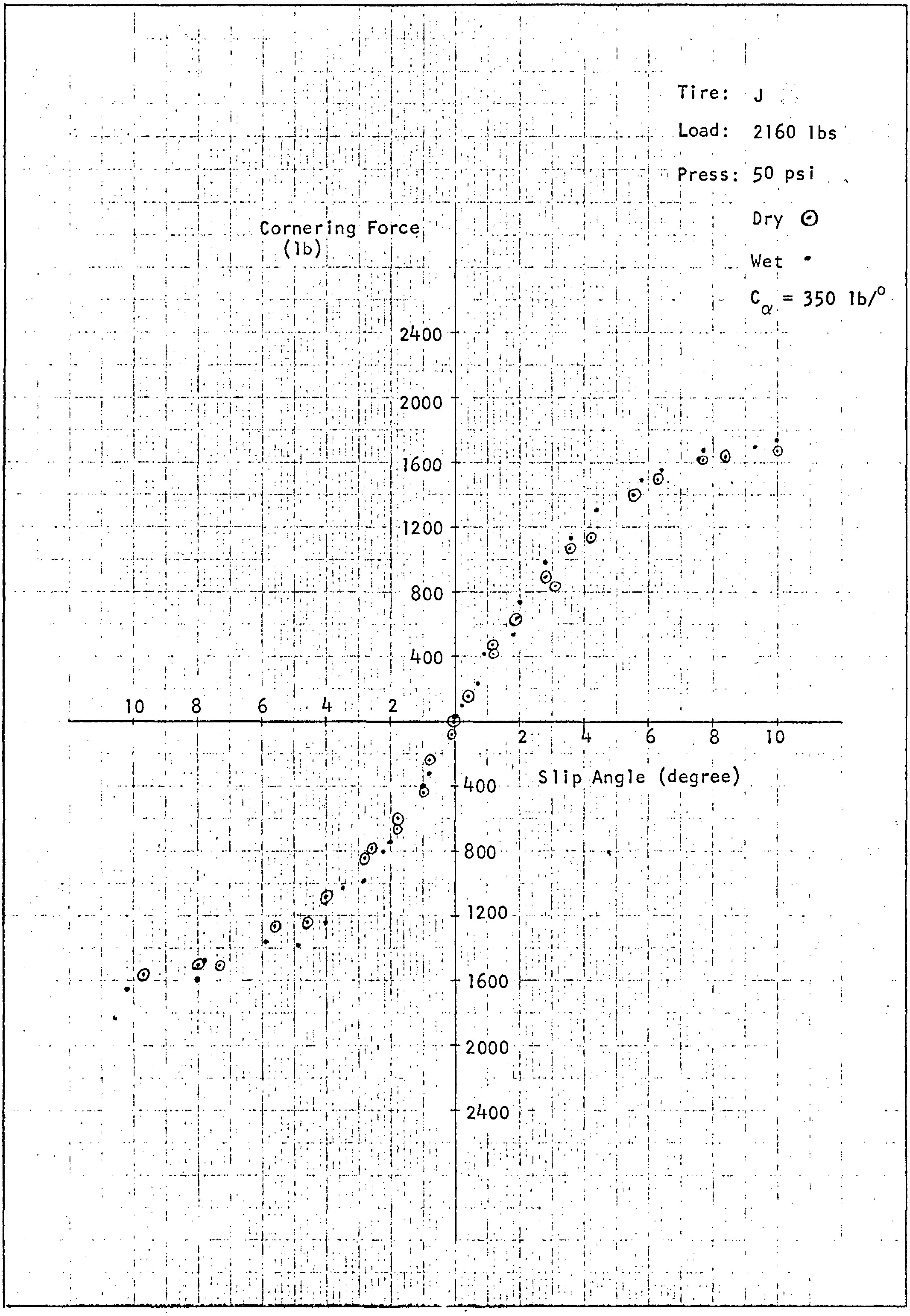
Tire: J
Load: 1504 psi
Press: 35 psi
Dry
Wet
C_{α} = 243 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400

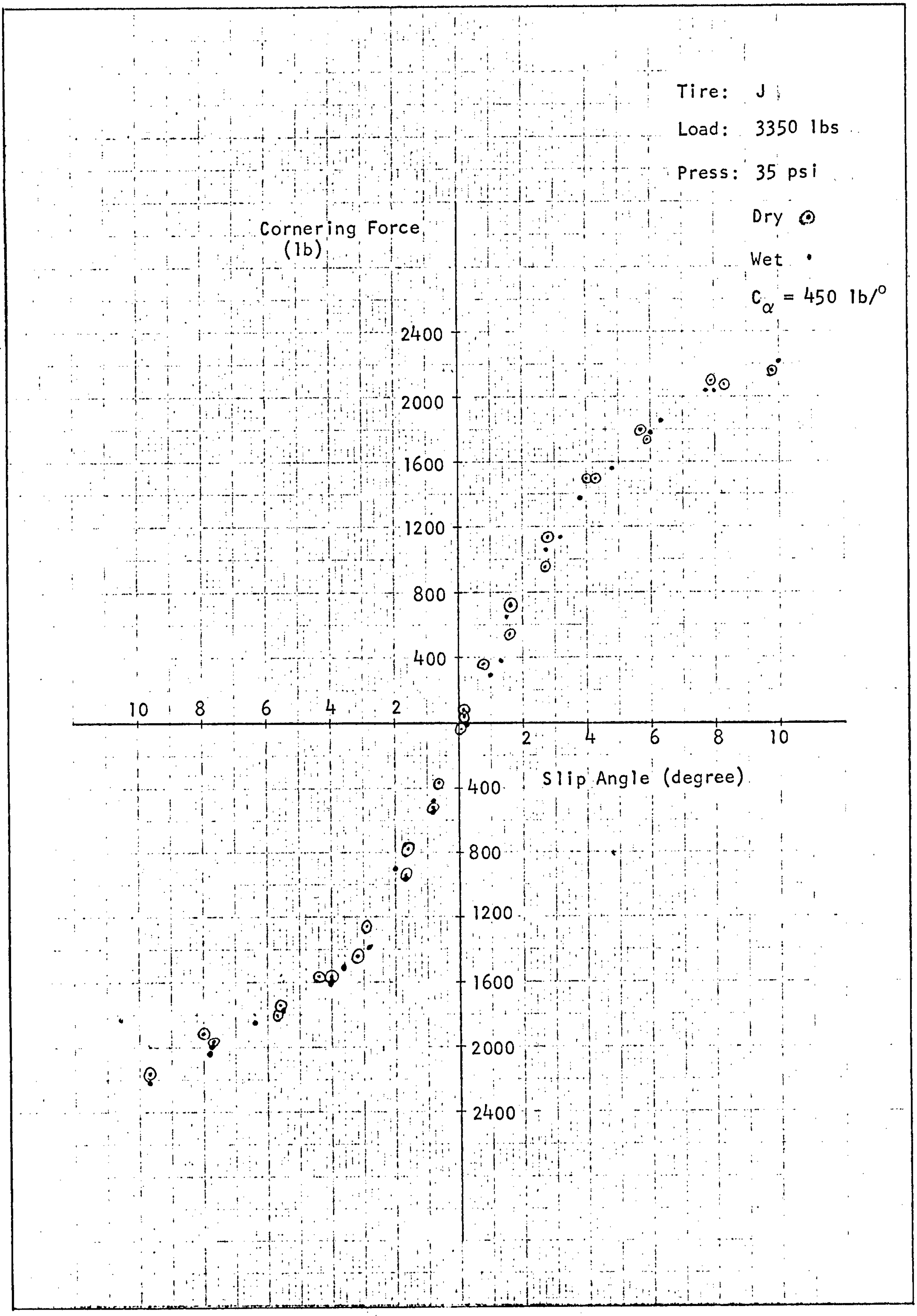


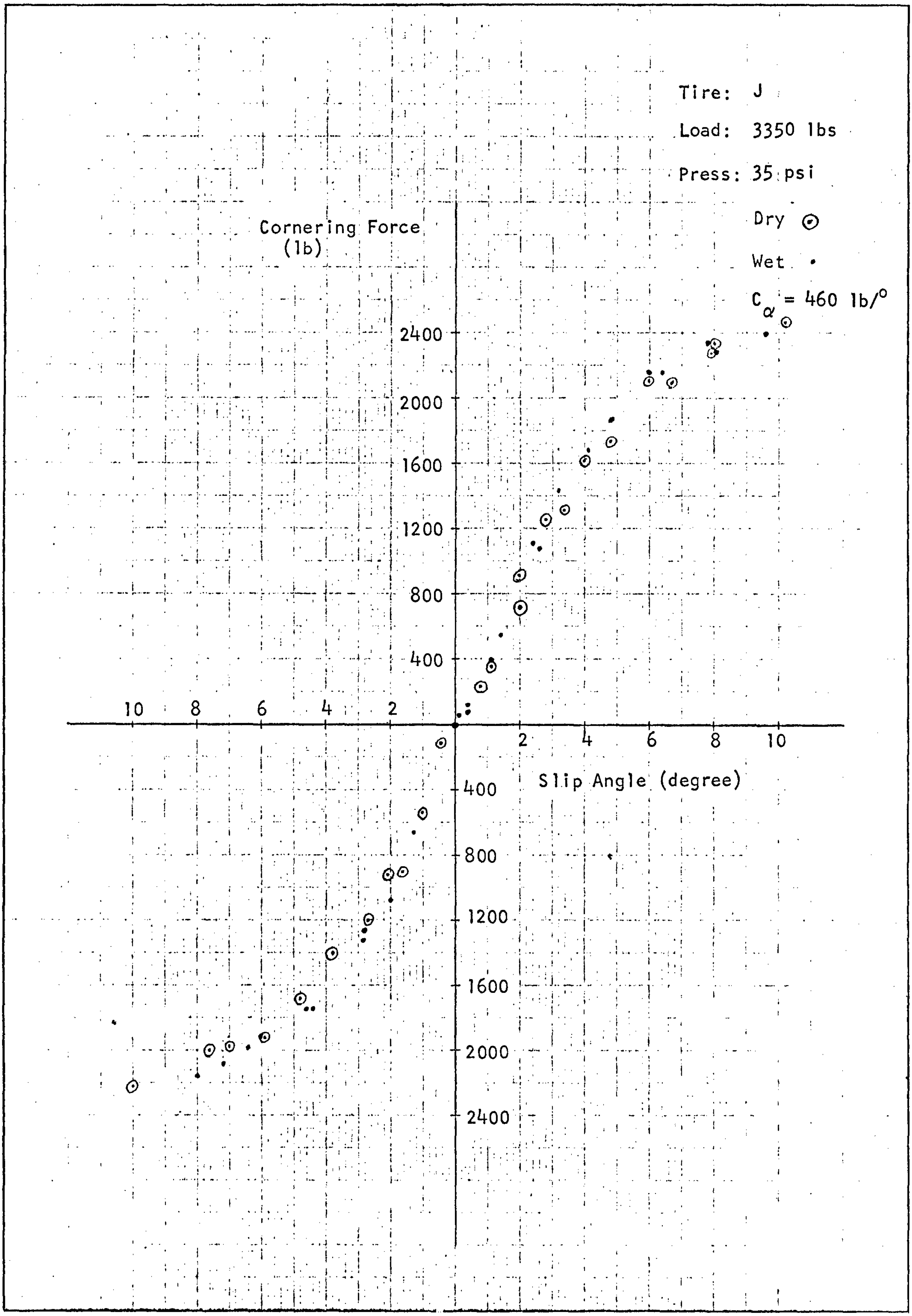
Tire: J
Load: 1504 lbs.
Press: 50 psi
Dry
Wet
C_α = 245 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: J
Load: 2160 lbs
Press: 15 psi
Dry
Wet
C_α = 267 lb/°
Cornering Force (lb)
Slip Angle (degree)
2400
2000
1600
1200
800
400
10
8
6
4
2


Tire: J
Load: 2160 lbs.
Press: 35 psi
Dry
Wet
C_α = 320 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: J
Load: 2160 lbs
Press: 50 psi
Dry ⊙
Wet •
C_α = 350 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
0
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: J
Load: 3350 lbs
Press: 35 psi
Dry
Wet
C_α = 450 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10
8
6
4
2
2
4
6
8
10
Slip Angle (degree)
400
800
1200
1600
2000
2400


Tire: J
Load: 3350 lbs
Press: 35 psi
Dry
Wet
C_α = 460 lb/°
Cornering Force (lb)
2400
2000
1600
1200
800
400
10 8 6 4 2
2 4 6 8 10
Slip Angle (degree)
400
800
1200
1600
2000
2400

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Ten sets of tires with nine different off-road tread patterns were tested on a paved surface using a towed, instrumented trailer to measure their cornering characteristics (wet and dry) and their braking performance (wet, full skid).

The data obtained and a method for rank ordering is presented.

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